# *"Enhancing California's Water Resources Management and Decision Support System Through Remote Sensing of Precipitation"*


***Soroosh Sorooshian***

*Center for Hydrometeorology and Remote Sensing*
*University of California Irvine*

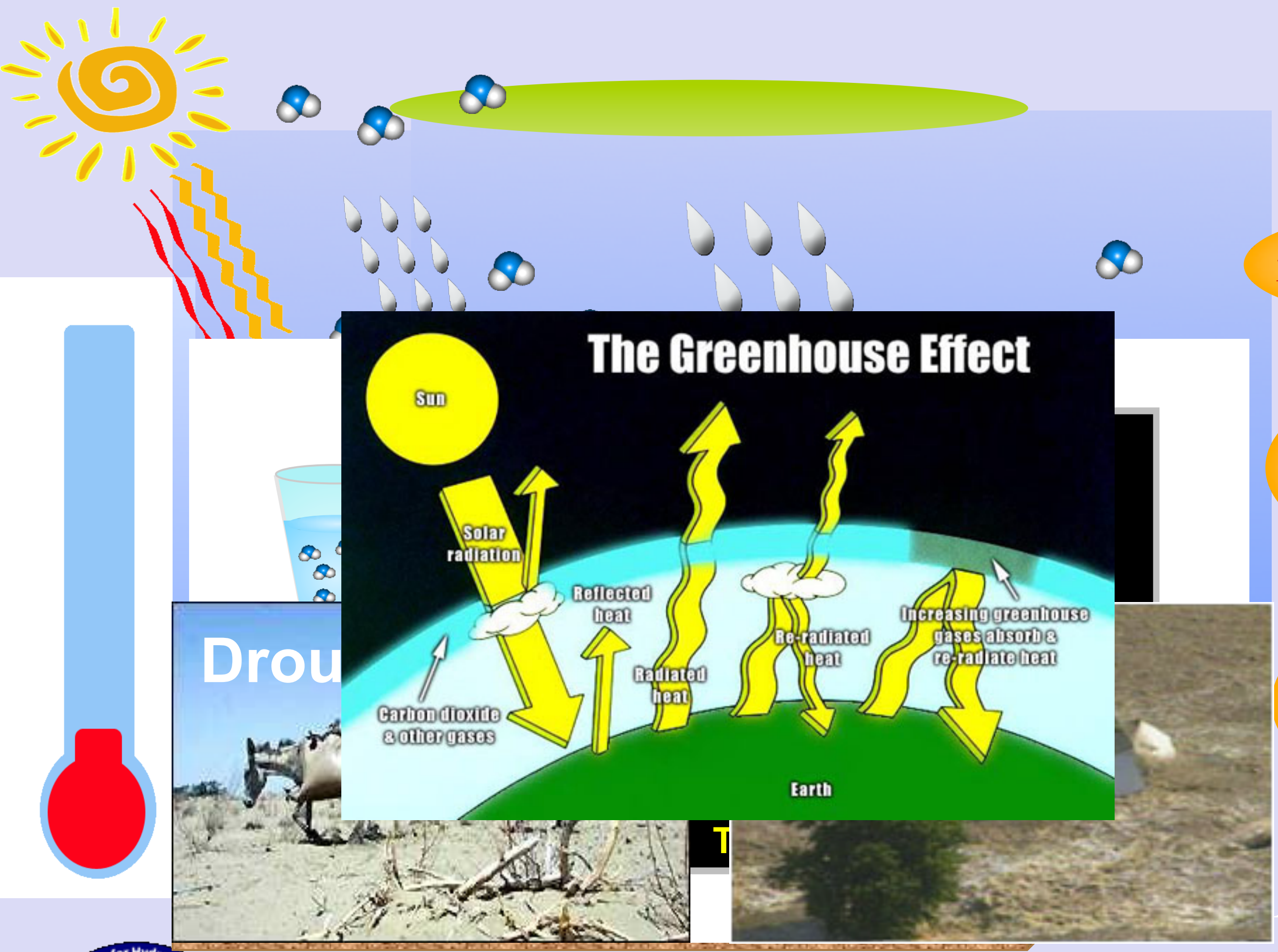

***NASA and DWR Remote Sensing and drought Monitoring and Response Workshop***

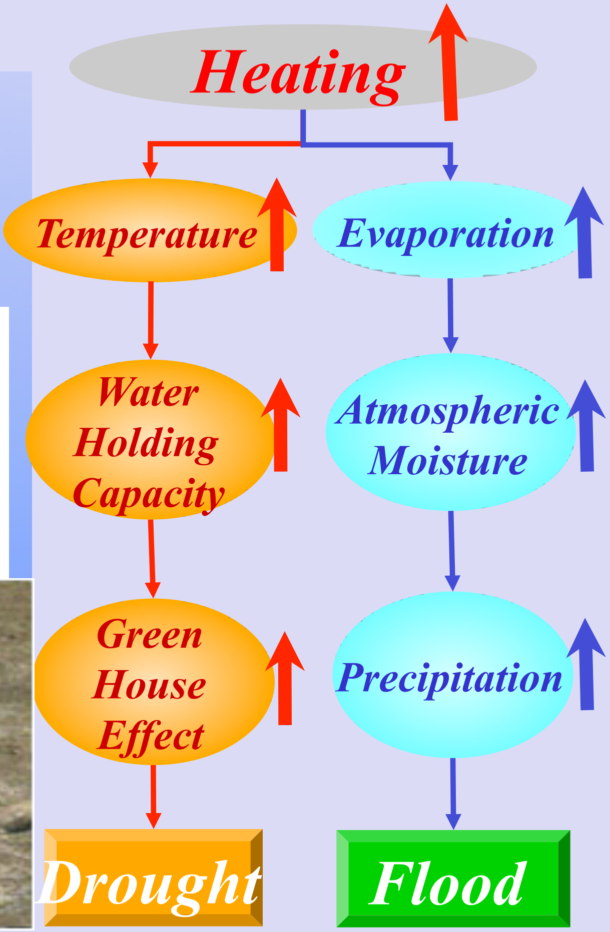
***Sacramento CA: Feb. 25th 2014***

# University of California Irvine (UCI) Research Team: Present and Past


***and many more ...***

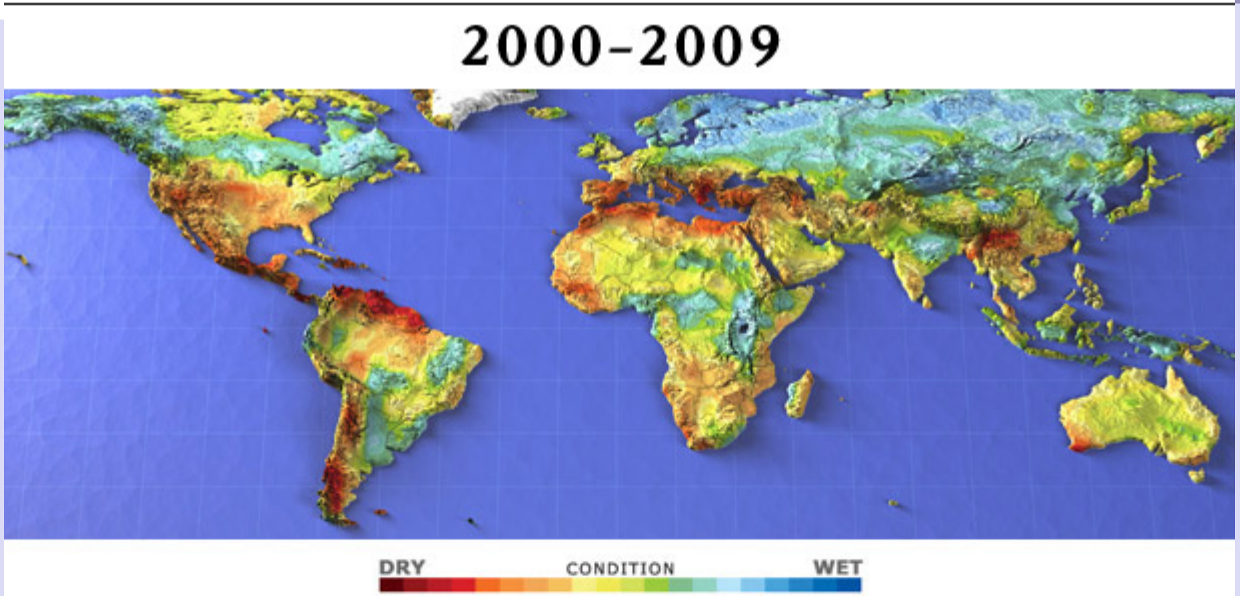
# Global Warming And Hydrologic Cycle Connection

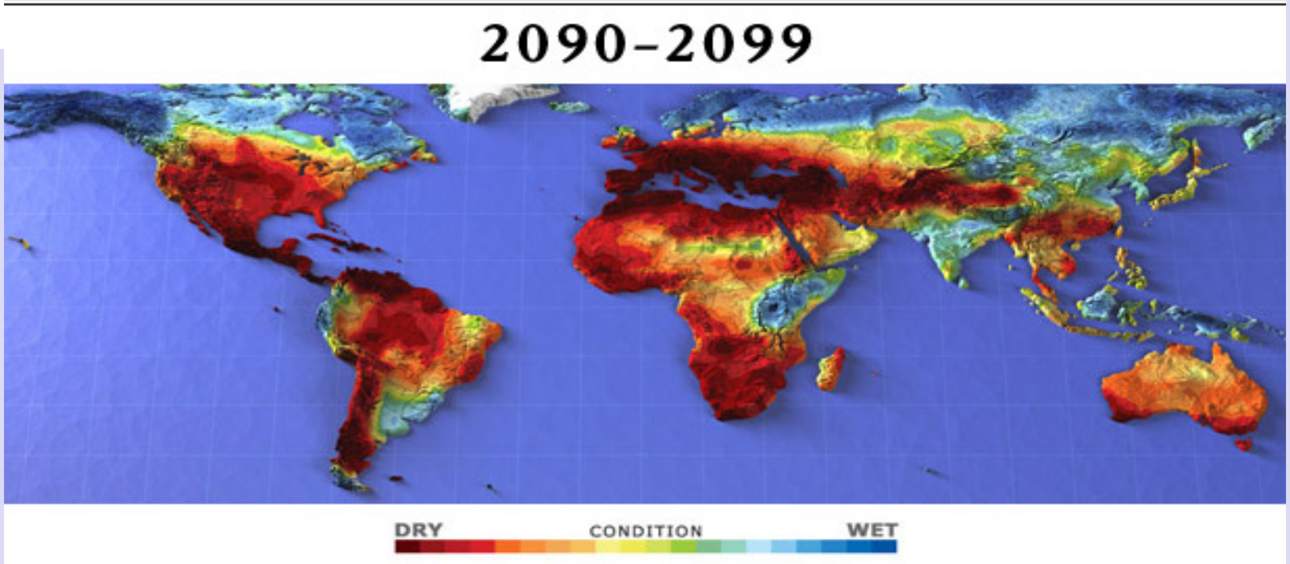



Created by: Gi-Hyeon Park
Center for Hydrometeorology and Remote Sensing, University of California, Irvine

# *Global Climate: Past Decade and Prediction of End of 21st Centaury*

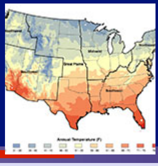



***Fair Question:***

*Where does all the additional Precipitation go?*

# *Regional Climate Trends and Scenarios: The Southwest U.S. USGCRP July 30, 2013*



## Precipitation

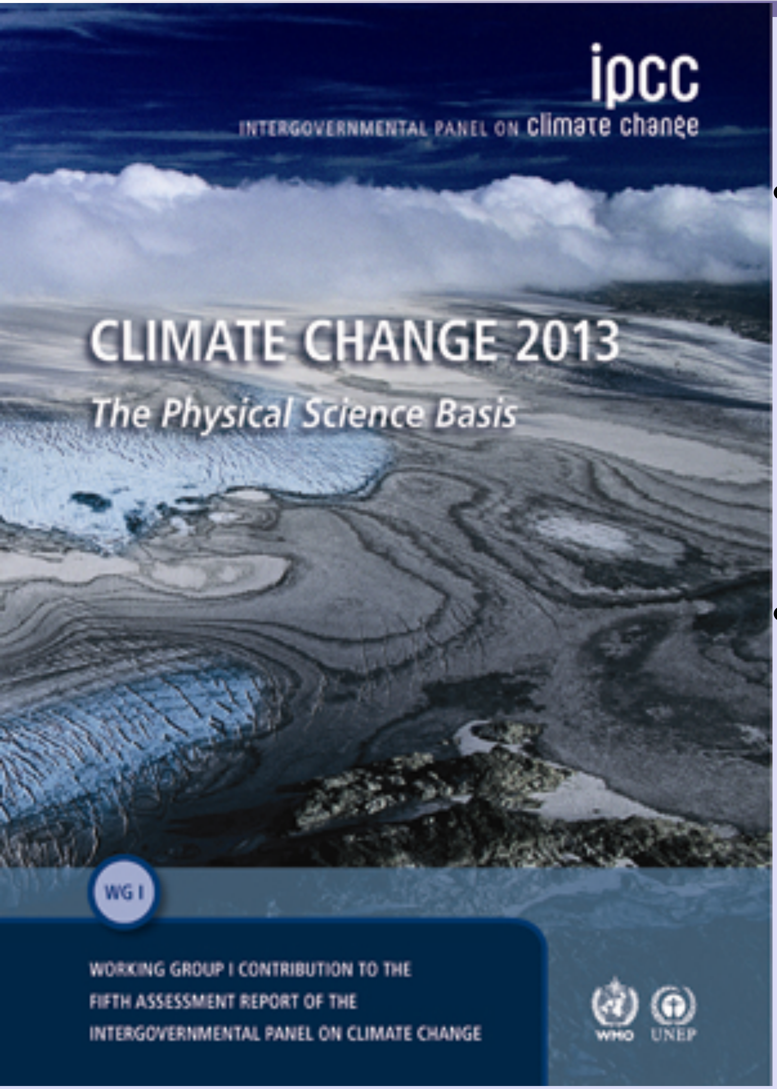
***• "Precipitation does not exhibit any obvious long-term trends for the Southwest U.S., except for Fall, which shows a slight upward trend. Trends are not statistically significant for any season.***

***• The region experienced its wettest conditions in the 1980s and 1990s (coinciding with a shift in Pacific climate in 1976, after which El Niño became much more frequent), but has dried in the last decade.***

## Extremes

***• There is not a statistically significant trend in the occurrence of extreme precipitation events in the Southwest."***

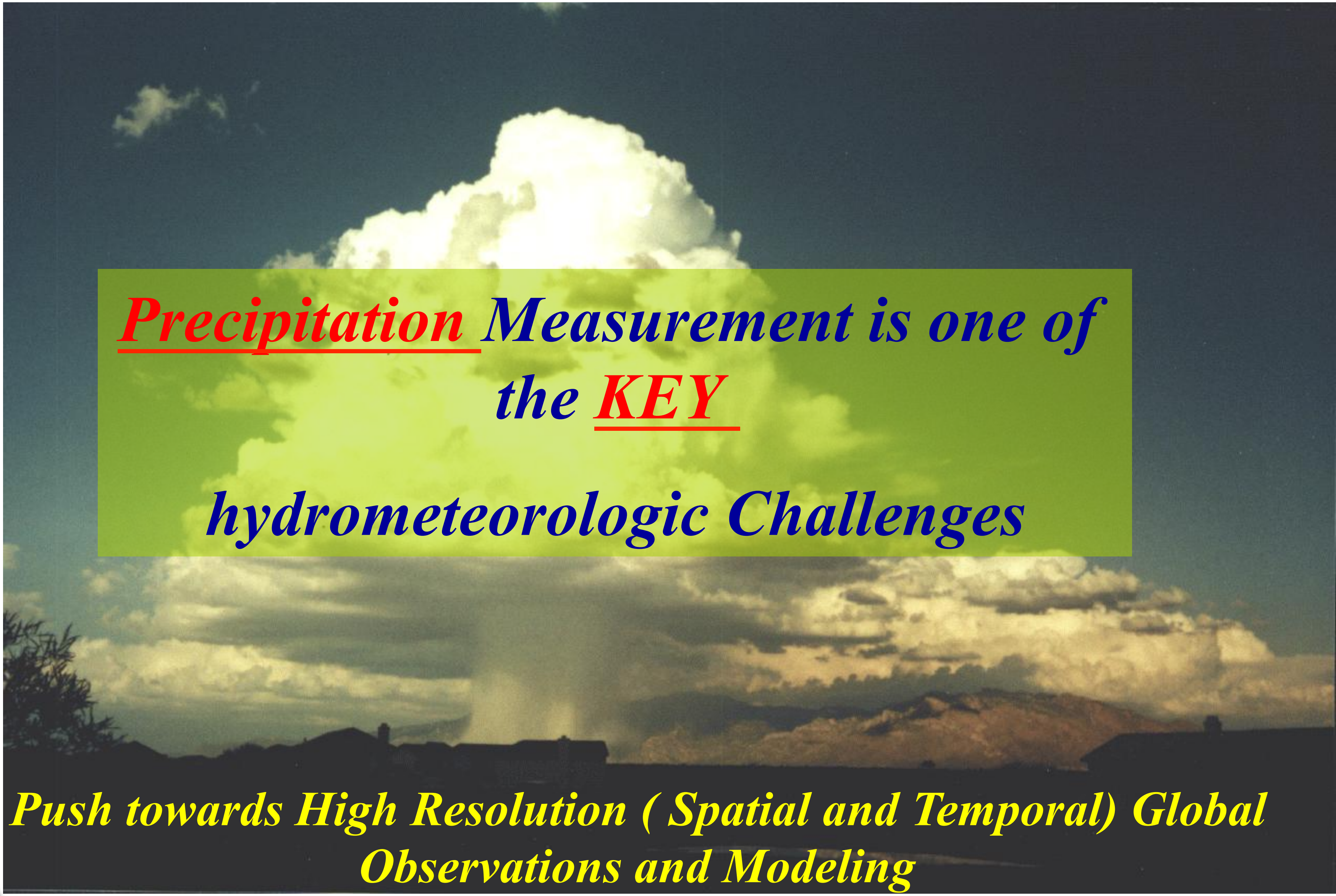
# *Recently Released IPCC Report (AR5) - Sept. 2013*




- ***"It is likely that since 1950 the number of heavy precipitation events over land has increased in more regions than it has decreased."***

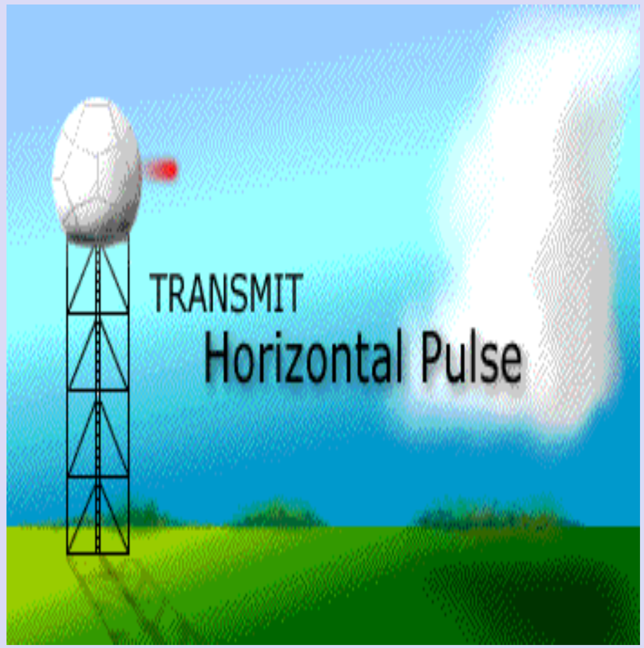
- ***"……… there continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale"***

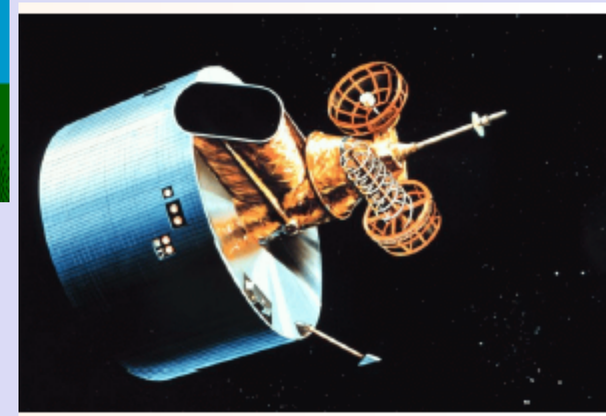
# A Key Requirement!



# Precipitation Observations: Which to trust??

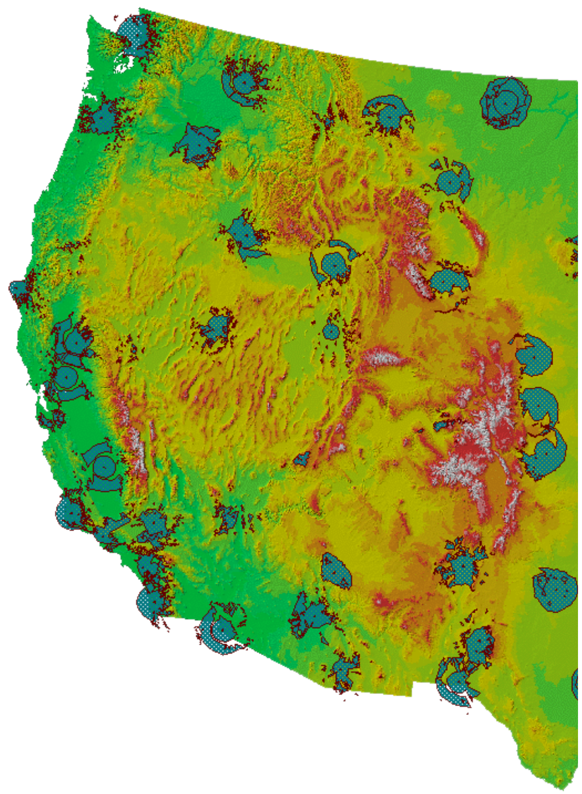
Rain Gauges



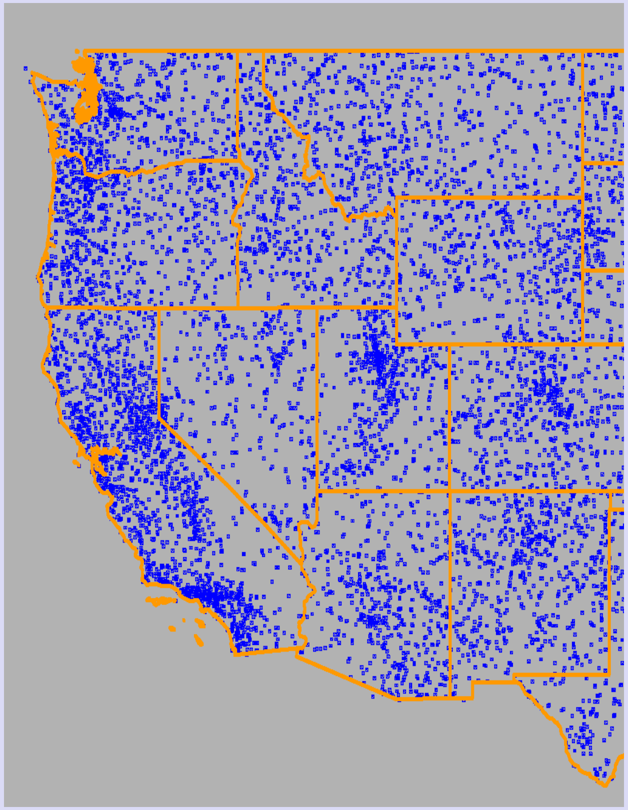
Satellite

# Coverage of the WSR-88D and gauge networks

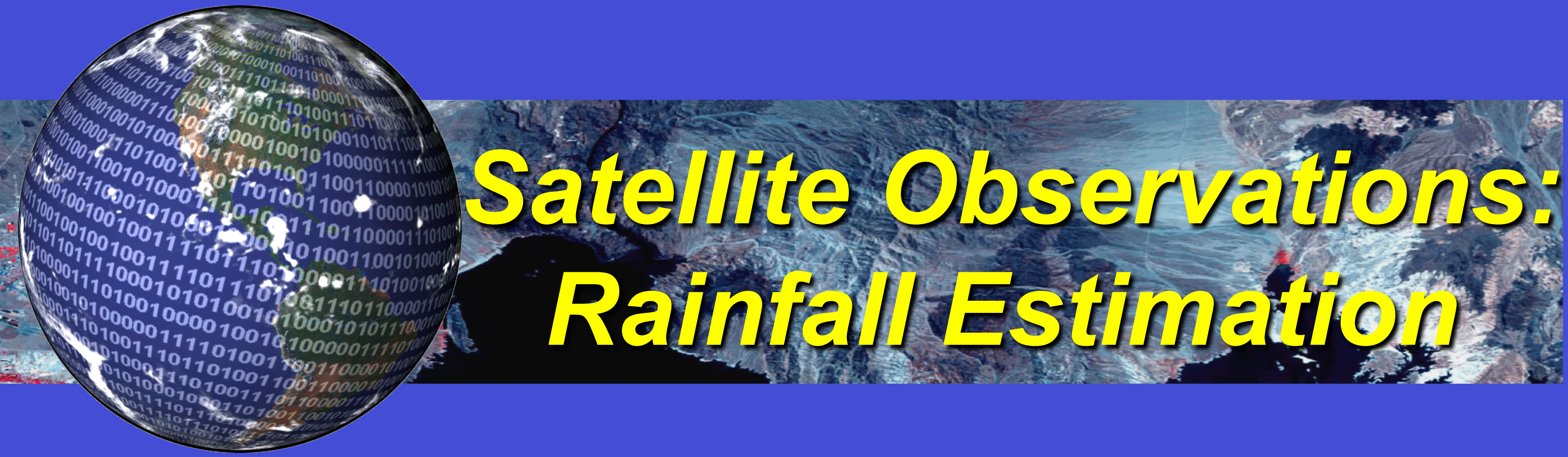


**1 km AGL**

*Maddox, et al., 2002*

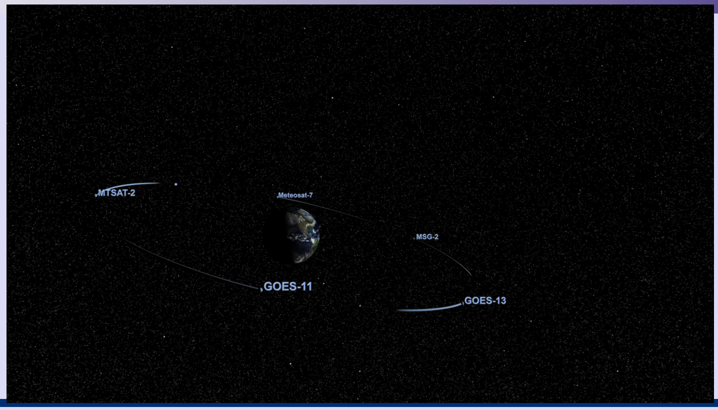


***Daily precipitation gages (1 station per 600 km^2 for Colorado River basin) hourly coverage even more sparse***

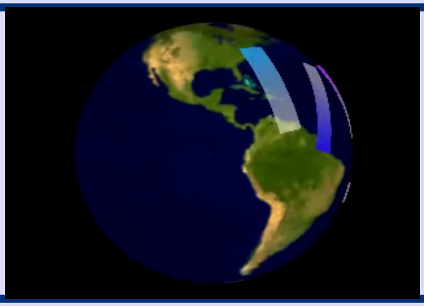


# Satellite Observations: Rainfall Estimation

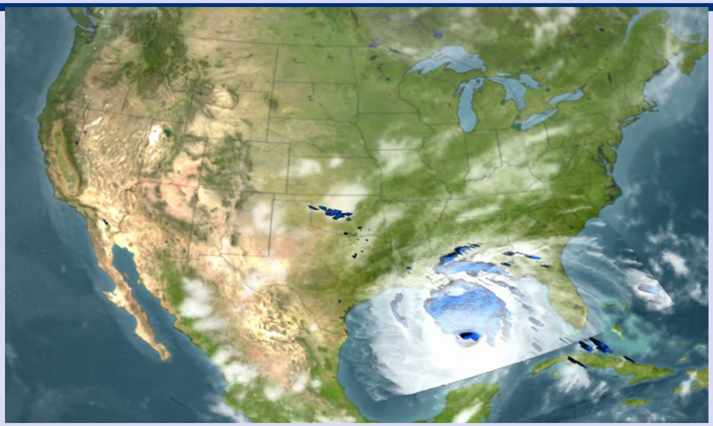
# Satellite Data for Precipitation estimation




*Geostationary IR*
*Cloud top data*
*15-30 minute temporal resolution*



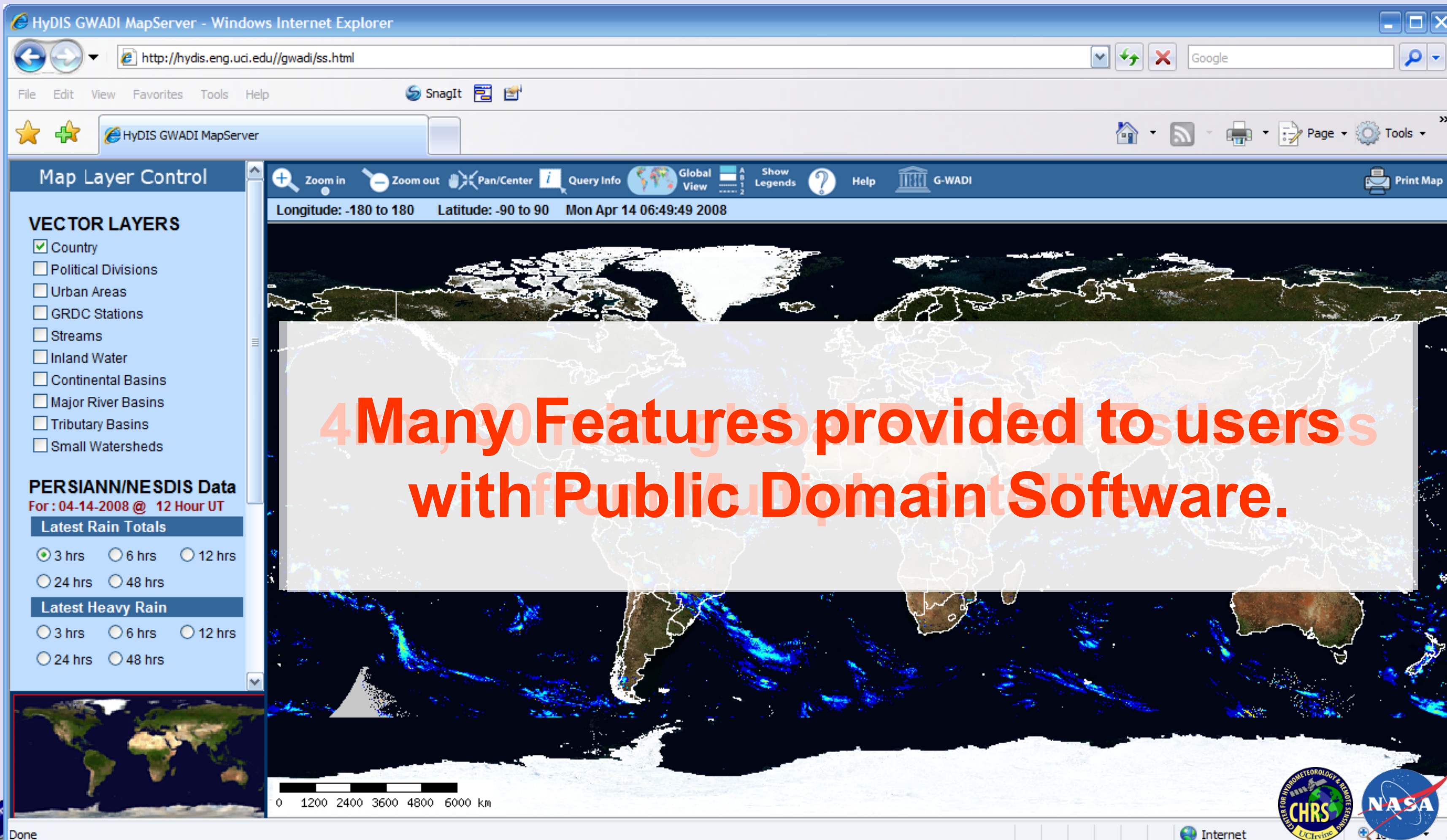
*Passive Microwave (SSM/I)*
*Some characterisation of rainfall*
*~2 overpasses per day per spacecraft, moving to 3-hour return time (GPM)*



*TRMM precipitation RADAR*
*3D imaging of rainfall*
*1-2 days between overpasses*
*( S-35°N-35 °)*

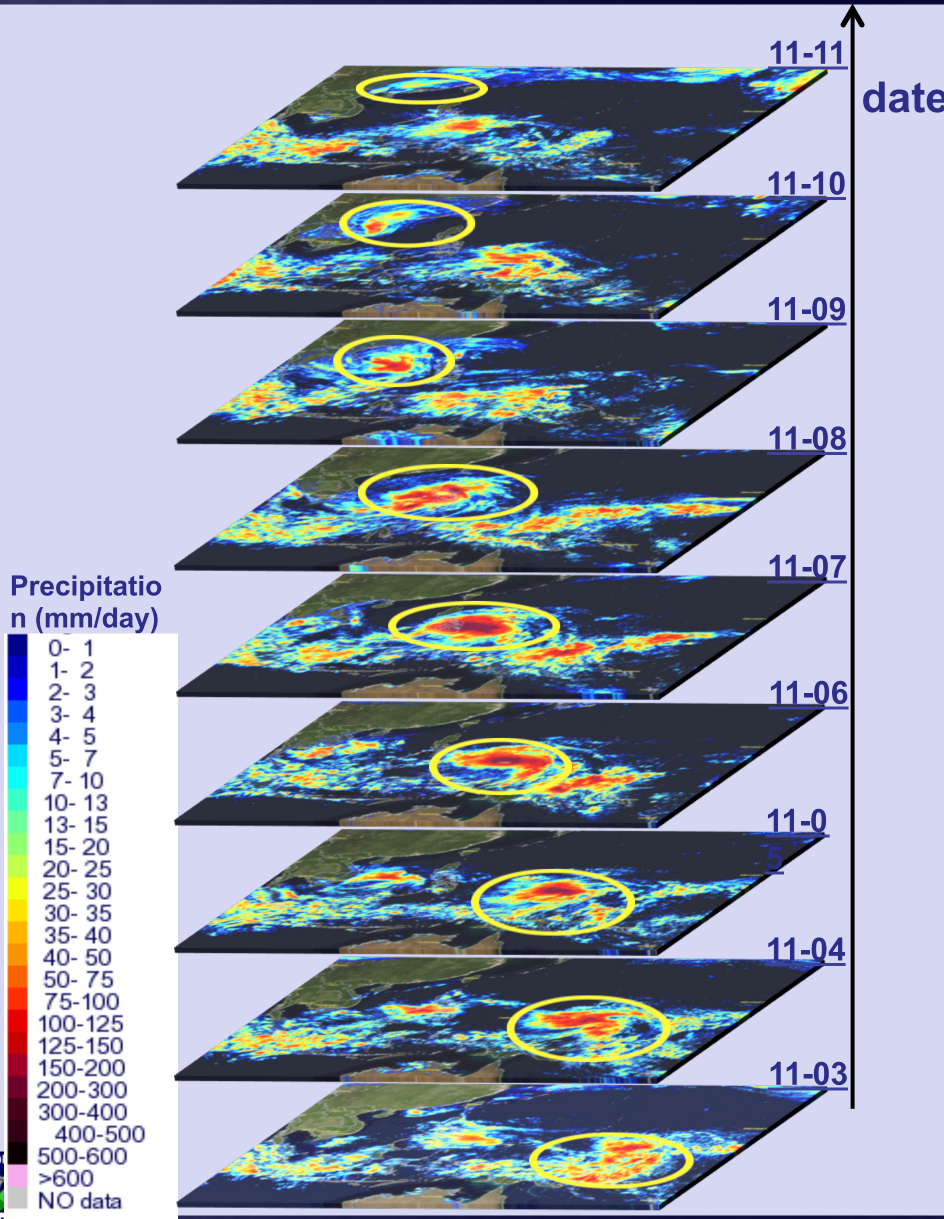
# Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)

# Real Time Global Data: Cooperation With UNESCO




**Many Features provided to users with Public Domain Software.**

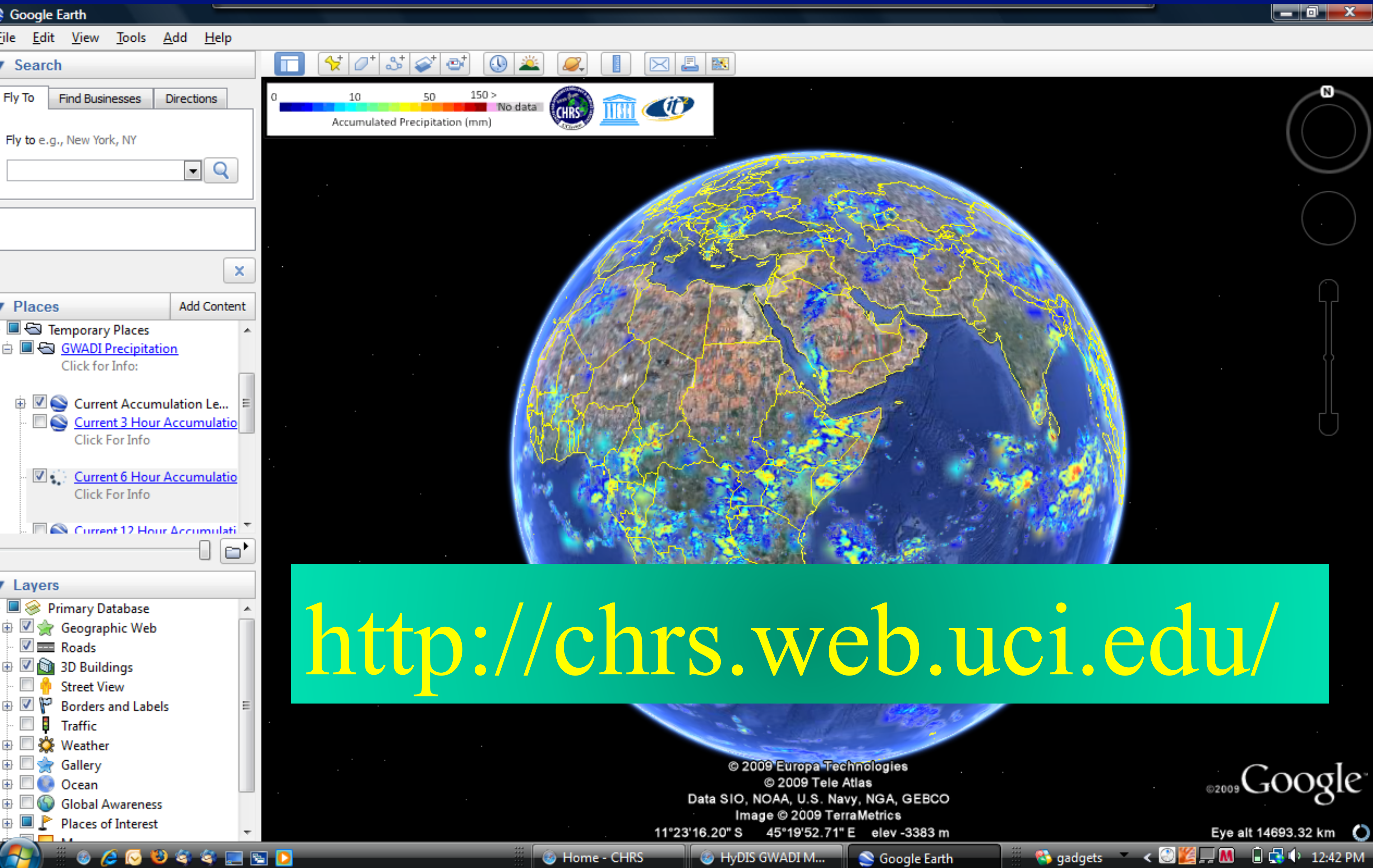
# *Daily precipitation (mm/day) of Typhoon Haiyan*




## Tracking characteristics of Typhoon Haiyan

| Date | Max Precip. Intensity (mm/d) | Total Volume (km3) |
|---|---|---|
| 11/3/2013 | 243.67 | 143.254 |
| 11/4/2013 | 265.65 | 114.829 |
| 11/5/2013 | 332.88 | 108.398 |
| 11/6/2013 | 328.25 | 150.658 |
| 11/7/2013 | 360.94 | 184.89 |
| 11/8/2013 | 320.47 | 126.253 |
| 11/9/2013 | 220.7 | 53.126 |
| 11/10/2013 | 130.69 | 24.673 |
| 11/11/2013 | 70.27 | 6.233 |

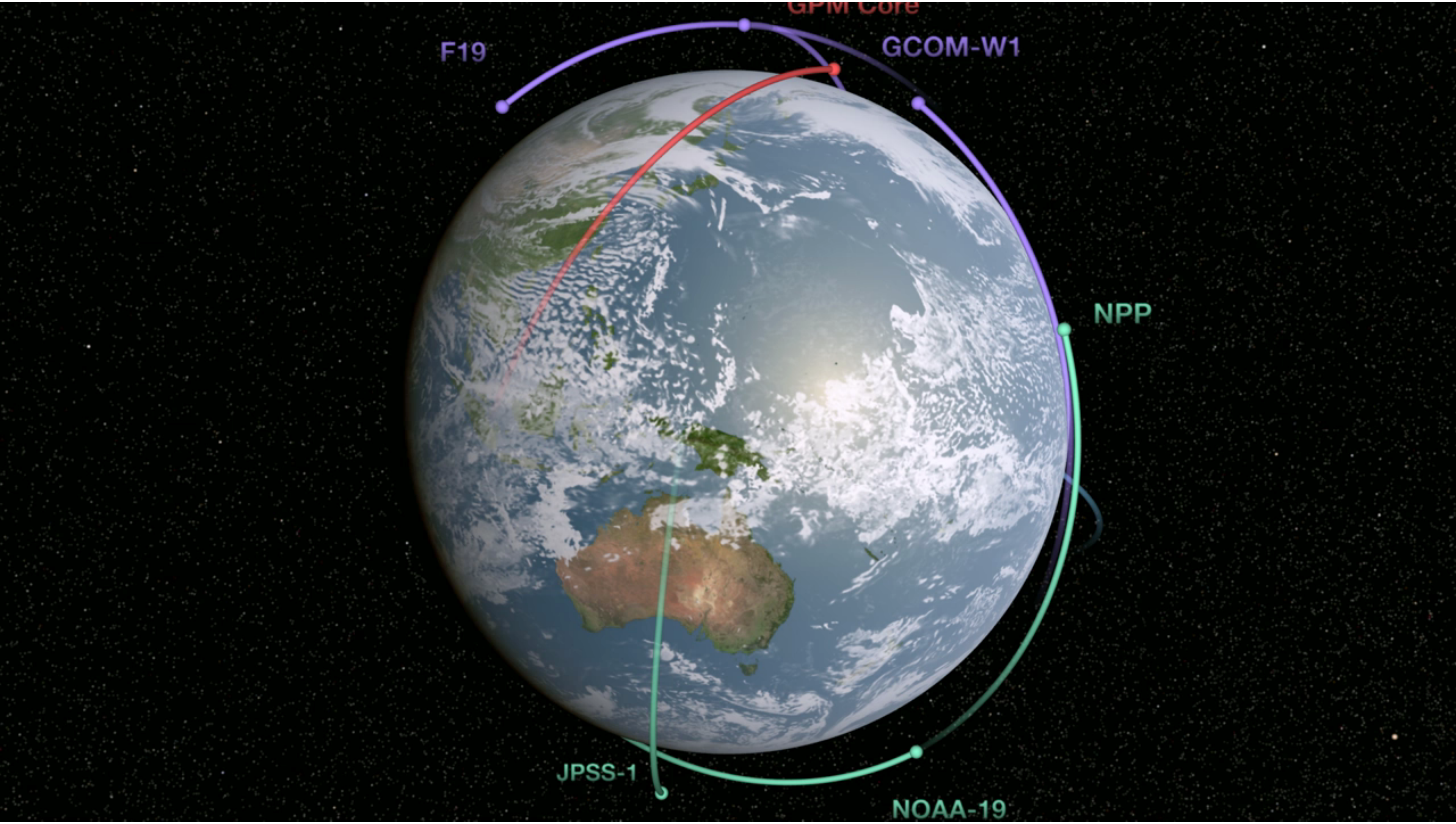
# *PERSIANN Satellite Product On Google Earth*




# http://chrs.web.uci.edu/

# GPM Animation

Courtesy: NASA's ESE



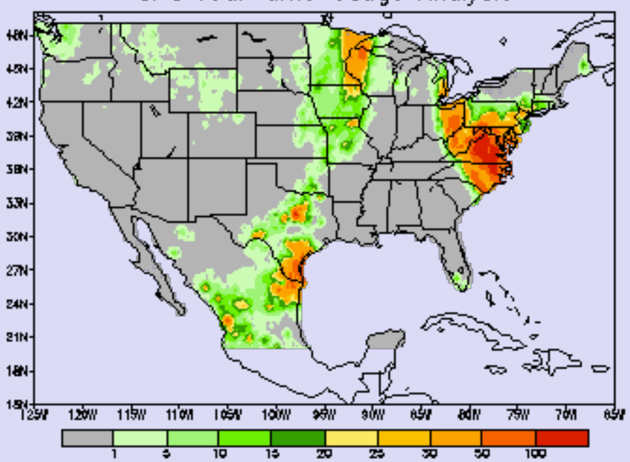
# Validation and Application of Satellite Products

# US Daily Precipitation Validation Page

**http://www.cpc.ncep.noaa.gov/products/janowiak/us_web.html**

13Z 19Sep2003 thru 12Z 19Sep2003
Data on 0.25 deg grid (UNITS are mm/day)

CPC real-time Gauge Analysis



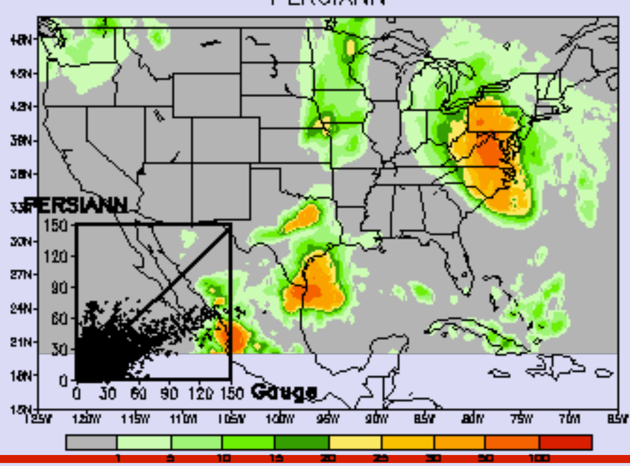

| | (G) gauge | (S) PERSIANN | (R) radar |
|---|---|---|---|
| Number of points: | 13828. | 13828. | 13828. |
| # points w/rain: | 4249. | 4665. | 2971. |
| Mean rain rate: | 5.55 | 4.25 | 3.13 |
| Cond. rain rate: | 17.82 | 12.47 | 14.46 |
| Max. rain rate: | 181.99 | 79.07 | 131.45 |

| | G–S | G–R | R–S |
|---|---|---|---|
| Correlation: | 0.827 | 0.726 | 0.606 |
| Mean Absolute Error: | 3.63 | 3.42 | 3.35 |
| RMSE (mm/day): | 9.44 | 11.23 | 8.66 |
| RMSE (normalized): | 1.70 | 2.02 | 2.77 |
| Probability of Detection: | 0.746 | 0.654 | 0.855 |
| False Alarm Ratio: | 0.321 | 0.065 | 0.455 |
| Bias Ratio (rain:no rain): | 1.098 | 0.699 | 1.570 |
| Heidke Skill Score: | 0.574 | 0.692 | 0.546 |
| Hanssen–Kuipers Score: | 0.589 | 0.634 | 0.660 |
| Equitable Threat Score: | 0.402 | 0.528 | 0.376 |

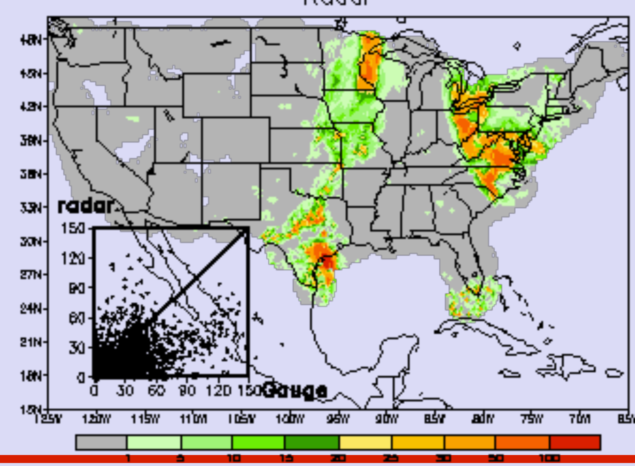
| gauge \ PERSIANN | < 1 | ≥ 1 |
|---|---|---|
| < 1 | 8082. | 1497. |
| ≥ 1 | 1081. | 3168. |

| gauge \ radar | < 1 | ≥ 1 |
|---|---|---|
| < 1 | 9386. | 193. |
| ≥ 1 | 1471. | 2778. |

PERSIANN




Radar




*Center for Hydrometeorology and Remote Sensing, University of California, Irvine*

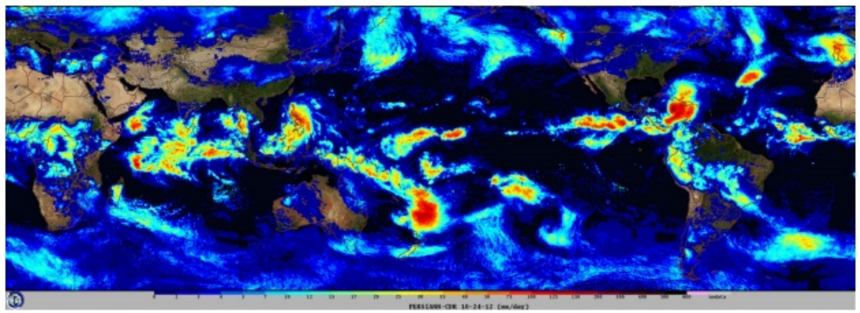
# PERSIANN ... Record

NOAA'S NATIONAL CLIMATIC DATA CENTER

# NOAA's Climate Data Record (CDR) Program

## Precipitation Estimation from Remote Sensing Information using Artificial Neural Network

# PERSIANN



### *PERSIANN* Climate Data Record Specifications

- 0.25-deg * 0.25-deg (60°S–60°N latitude and 0°–360° longitude)
- Daily Product
- 1980–present
- Updated Monthly

### Inputs to the *PERSIANN* Climate Data Record

- GridSat-B1 CDR (IRWIN)
- GPCP 2.5-deg Monthly Data

### Some Uses of the *PERSIANN* Climate Data Record

- Climatologists can perform long-term climate studies at a finer resolution than previously possible.
- Hydrologists can use PERSIANN-CDR for rainfall-runoff modeling in regional and global scale, particularly in remote regions.
- Performing extreme Event Analysis (intensity, frequencies, and duration of floods and droughts).
- Water Resources Systems Planning and Management

### *PERSIANN* Climate Data Record

http://www.ncdc.noaa.gov/cdr/operationalcdrs.html

### Climate Data Record Program Information

http://www.ncdc.noaa.gov/cdr/index.html

www.climate.gov
www.ncdc.noaa.gov

*Protecting the past... Revealing the future*

September 2013

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NO...

Home | Operational CD...

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- Serving the Public
- Data
- Development Guidelines
- Contact Us

SEARCH NCDC

## News

Congratulations Cheng-Zhi...

2013 CDR Annual Meetings Presentations now availabl...

...n Environmental Satellites: Interim ...ated. The first step in establishing ...e dataset itself, and supporting ...opers Guidelines.

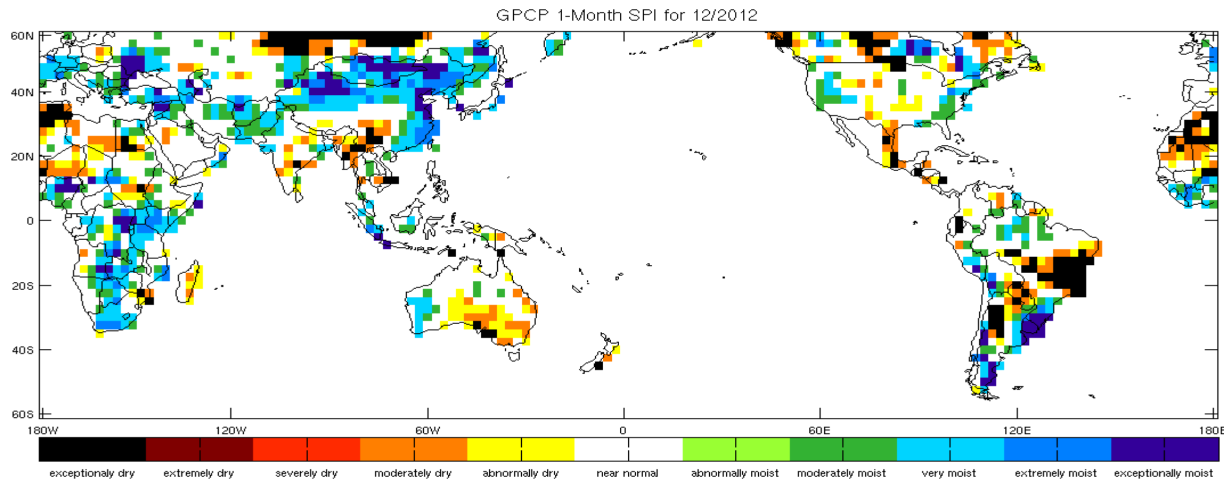
...Atmospheric, Oceanic, and ...eratures) that have been improved ...DRs are geophysical variables ...specific to various disciplines. ...utput.

| ...rce ...de | Documentation |
|---|---|
| | Algorithm Description<br>Data Flow Diagram<br>Maturity Matrix |
| | Algorithm Description<br>Data Flow Diagram<br>Maturity Matrix |
| | Algorithm Description<br>Data Flow Diagram<br>Maturity Matrix |
| | Algorithm Description<br>Data Flow Diagram<br>Maturity Matrix |
| | Algorithm Description<br>Data Flow Diagram<br>Maturity Matrix |

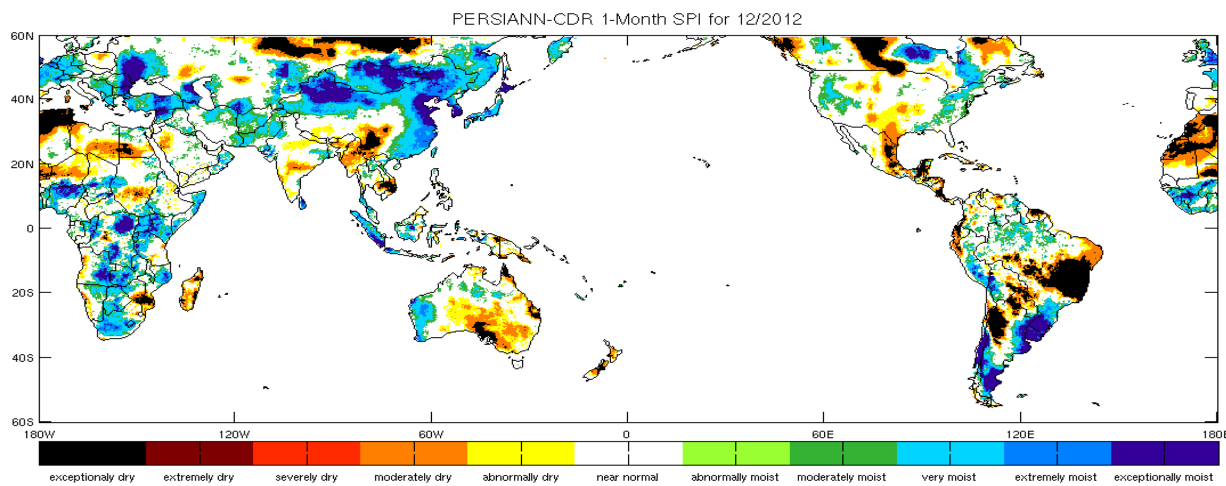
# Global Drought Monitoring

Monitoring global “abnormal” wetness and dryness conditions using Standard Precipitation Index (SPI) method from GPCP 2.5-deg monthly (top) and PERSIANN-CDR 0.25-deg daily (bottom) for the period of 1983-2012. NOTICE the difference in spatial resolution

**GPCP 2.5-deg monthly**

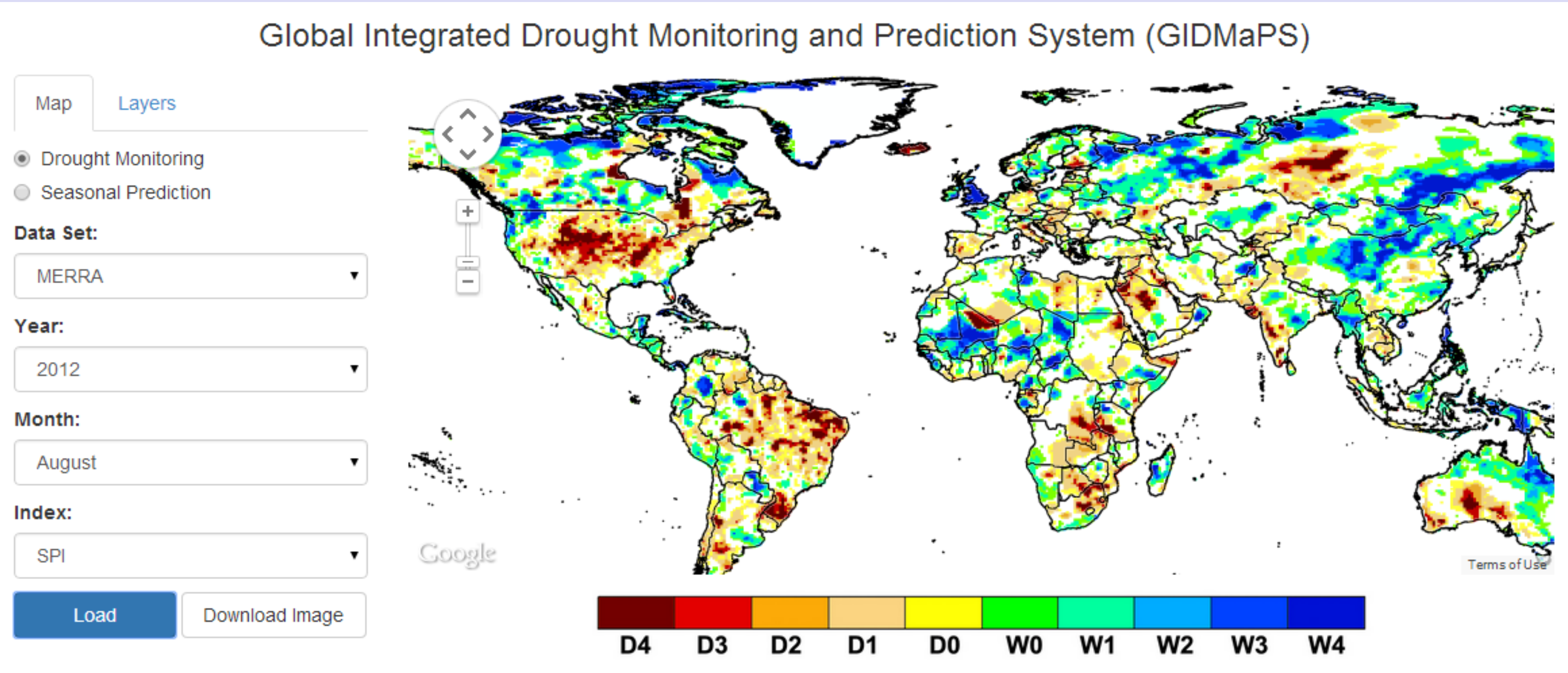



**PERSIANN-CDR 0.25-deg daily**




***H. Ashouri***

# UC-I Global Drought Monitoring System

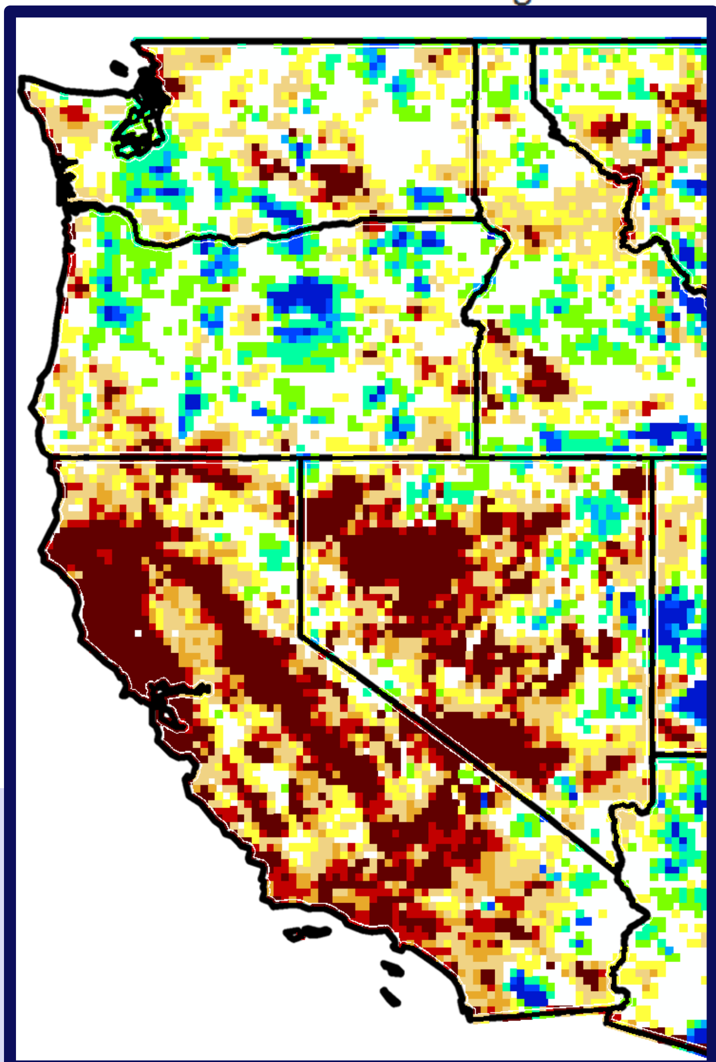


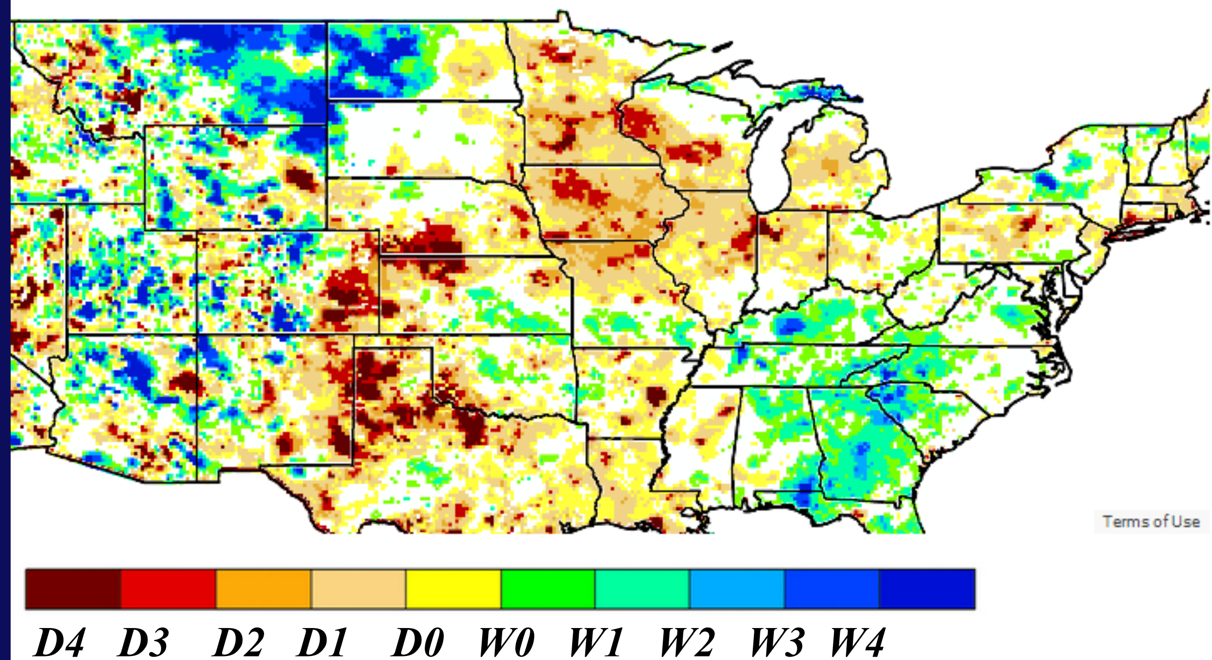

**http://drought.eng.uci.edu/**

*A. AghaKouchak Group*

# UC-I Global Drought Monitoring System

Global Integrated Drought Monitoring and Prediction System (GIDMaPS)





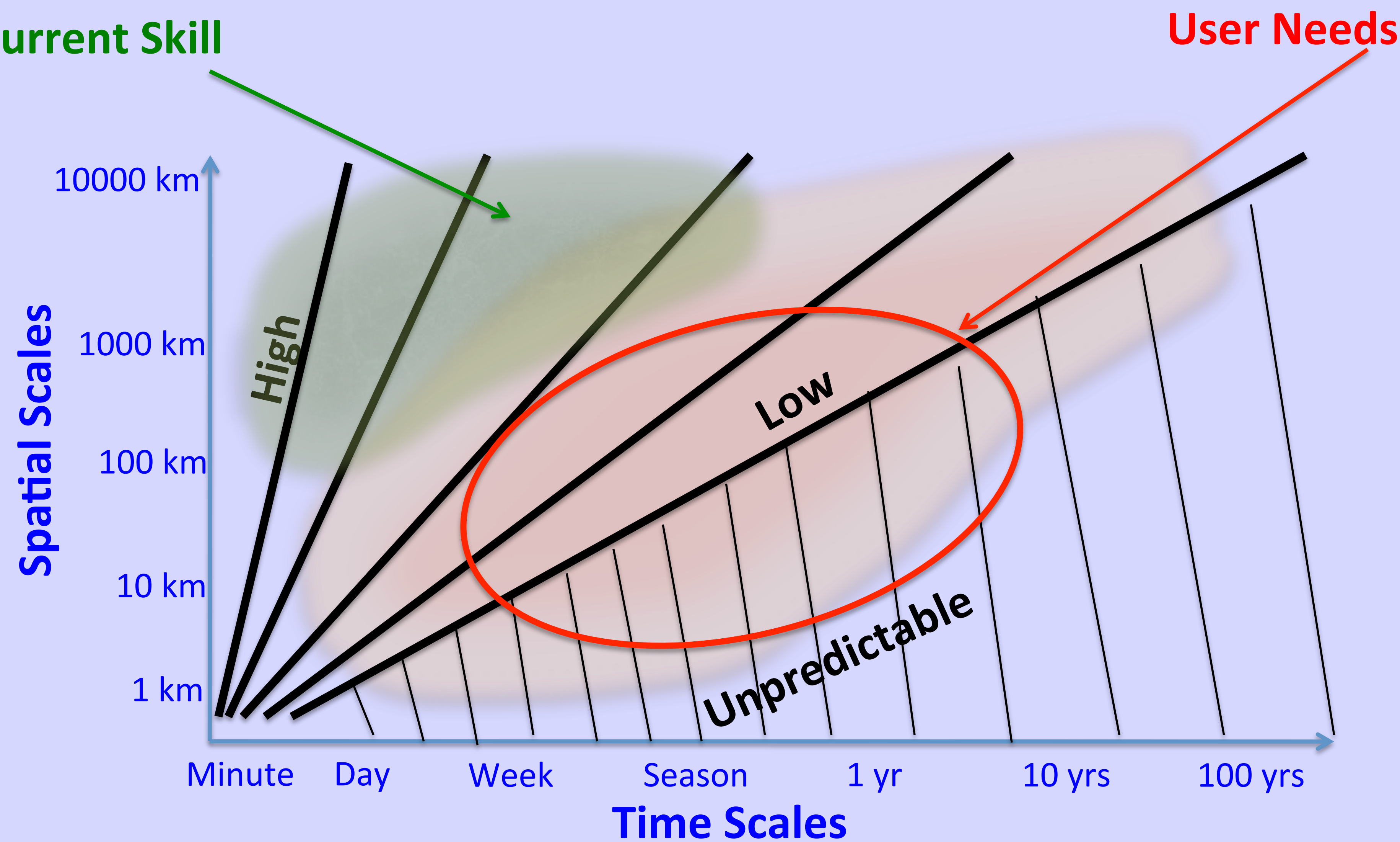

**http://drought.eng.uci.edu/**

*A. AghaKouchak Group*

# Hydrologically-Relevant Climate Variables

## What Do Models Tell Us About Future Precipitation Patterns and Amounts?

# *Drought Predictability*




Provided by Siegfried Schubert 2011

# Recent Evaluation of RCM/GCM over Western U.S.

**Wei Chu 2011**

Current period:1971-2000

Future period: 2041-2070

Spatial Res.: 50 km

Temporal Res.: daily

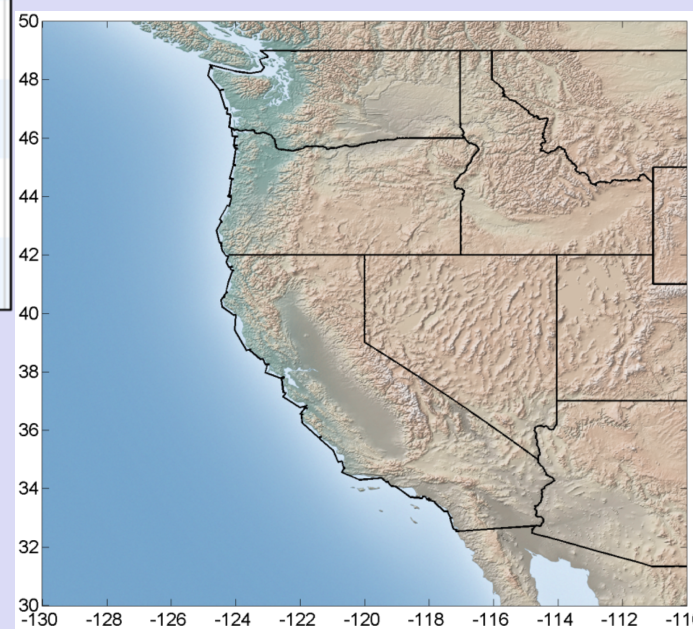
| Regional Models | Climate Models | | | |
|---|---|---|---|---|
| | GFDL | CGCM3 | HADCM3 | CCSM |
| CRCM | — | | — | — |
| ECP2 | | — | — | — |
| HRM3 | — | — | | — |
| MM5I | — | — | — | |
| RCM3 | — | | — | — |
| WRFG | — | — | — | |

<u>**Outputs of six RCM/GCM sets:**</u>

North American Regional Climate Change Assessment Program (NARCCAP)

Emissions Scenario:

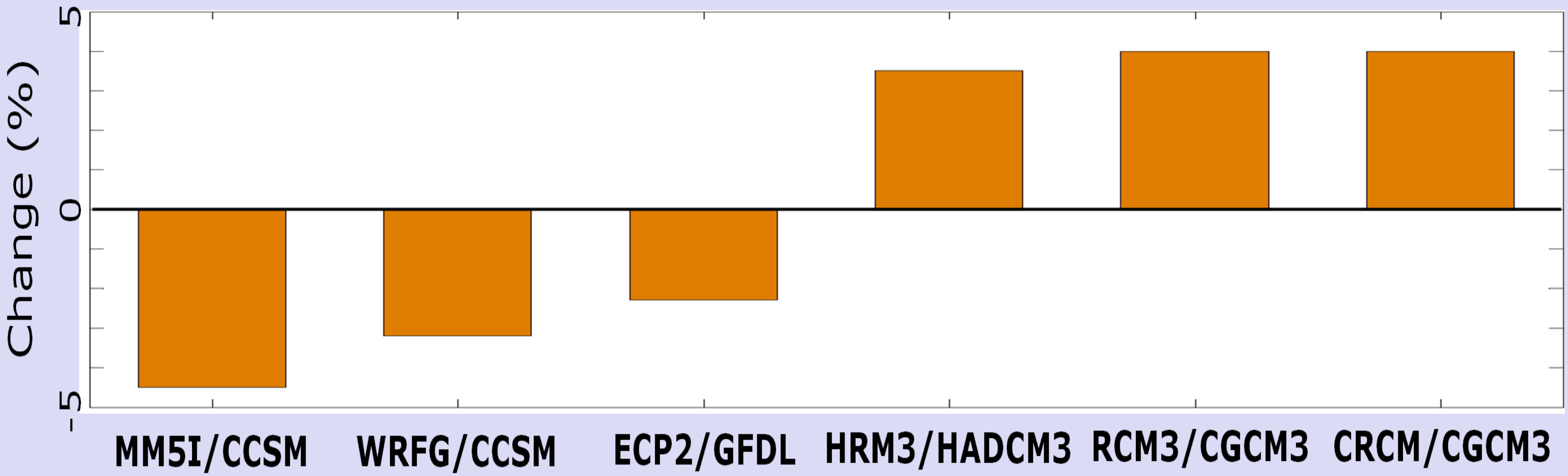
A2: regionally oriented and fast economic growth




**study region**

# *Recent Evaluation of RCM/GCM over Western U.S.*

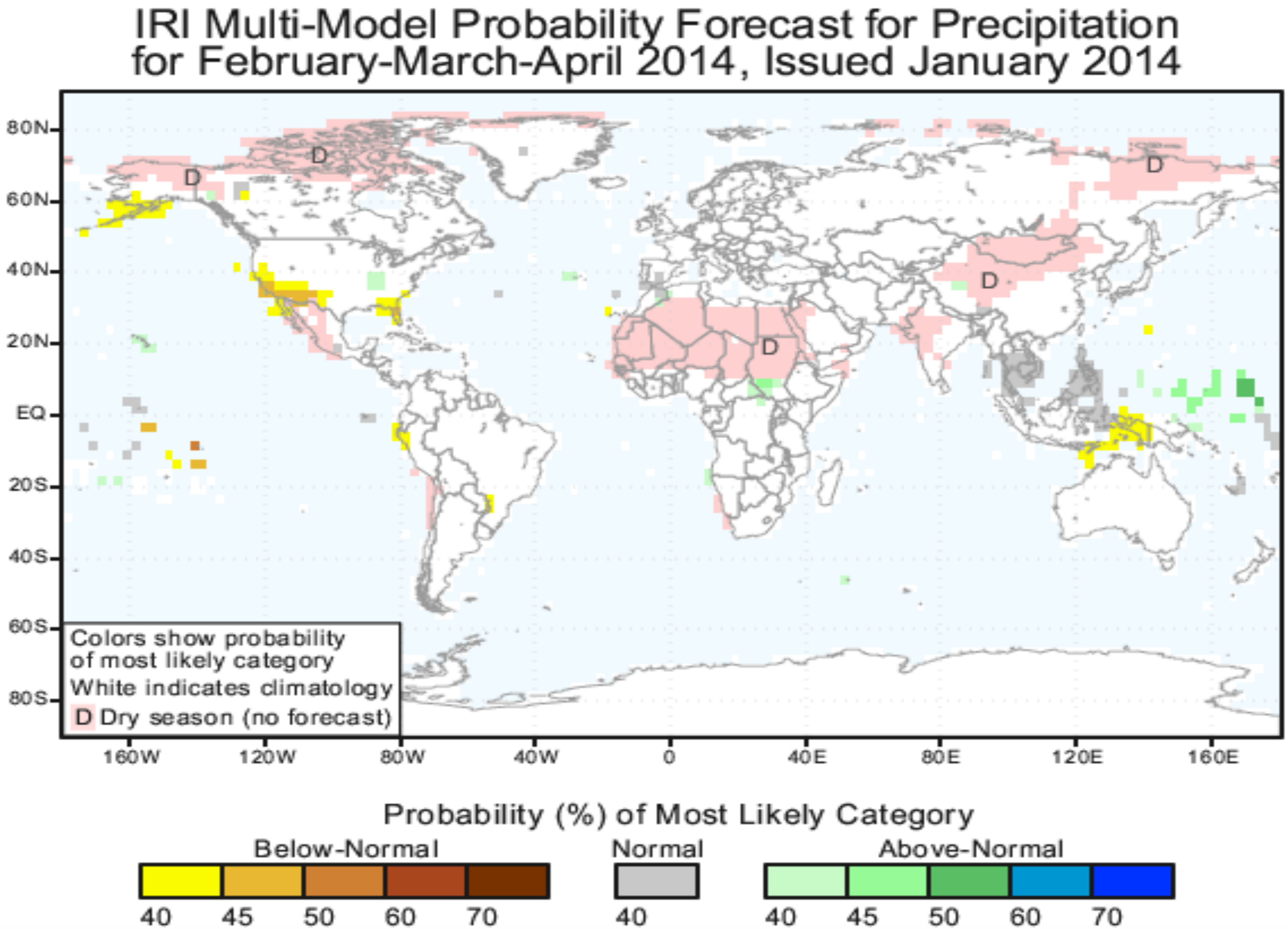
**Models indicate different signs and magnitudes of changes in the mean precipitation over the Western U.S. under the SRES A2 emissions scenario.**




Trend of area-average precipitation (comparing 2040-2070 with 1970-2000)

**Wei Chu 2011**

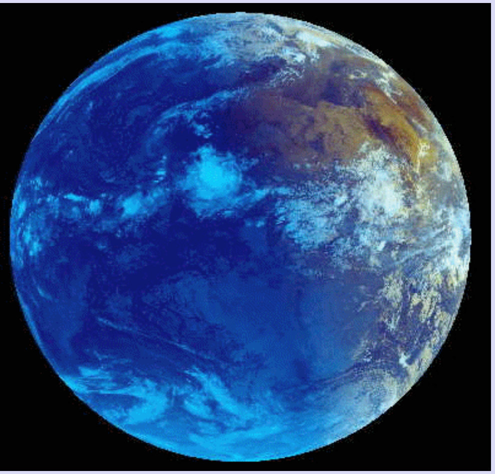
# IRI 3-Month Multi-Model Probability Precipitation Forecast



# Recent Assessment of Seasonal Climate Forecasts

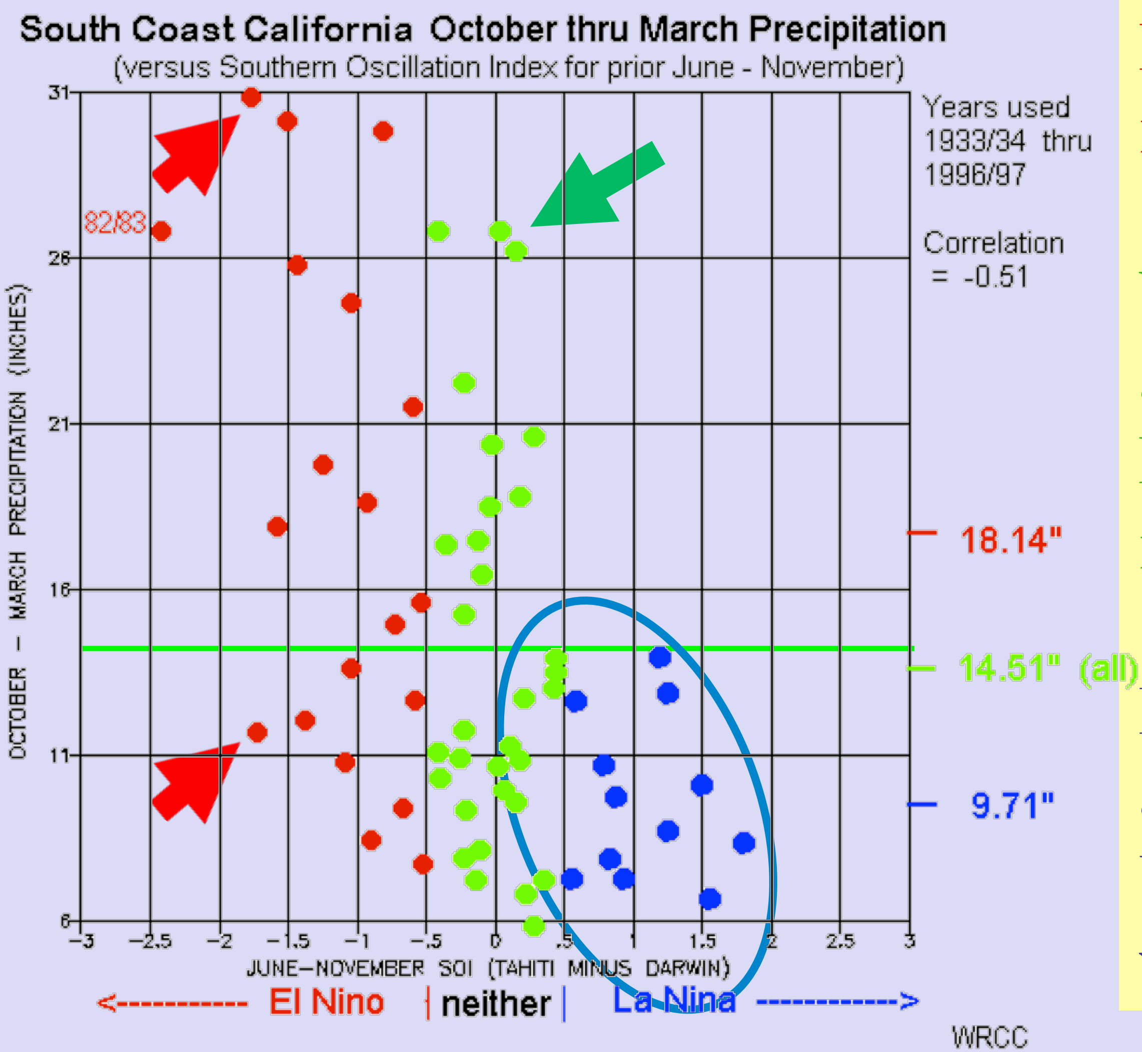
*Quoting from Science, Vol. 321, 15th August 2008*

*Livezey &Timofeyeva - BAMS, June 2008.*



- *“About the only time forecasts had any success predicting precipitation was for winters with an El Nino or a La Nina”*

# ENSO Example: South Coast California




**El Nino winters may be very wet.**

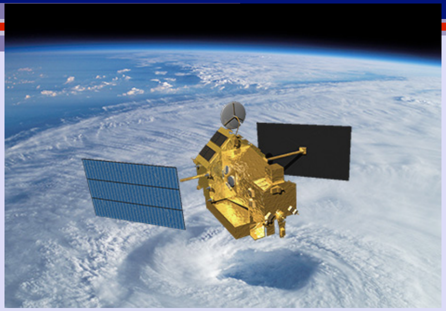
**Very wet winters are typically El Nino winters, but not always...**

**La Nina winters are typically dry, but reliably not wet.**

*Original idea of scatterplots By: Redmond and Koch 1991*

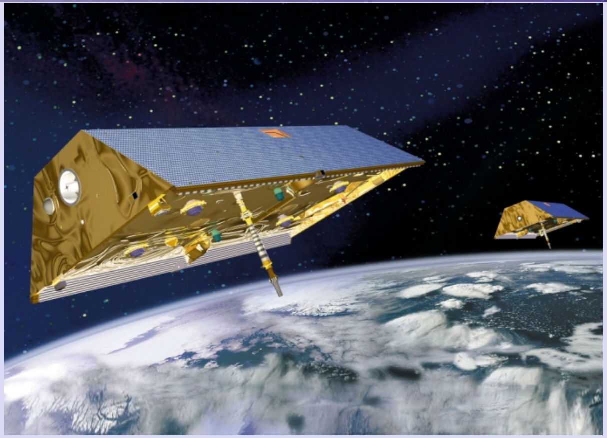
# Hydrologically - Relevant Remote Sensing Missions

**SMOS**
*ESA's Soil Moisture and Ocean Salinity (2009)*

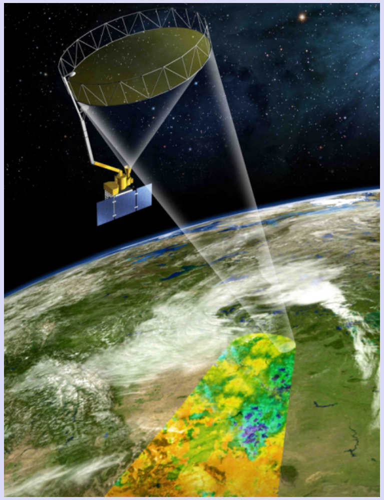


**TRMM**
*The Tropical Rainfall Measuring Mission*

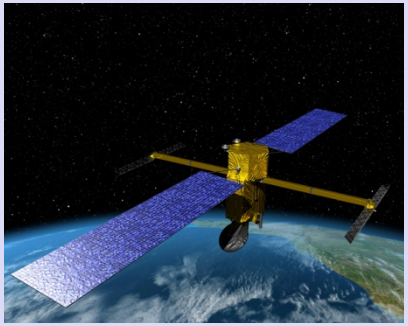
**GPM**
*Global Precipitation Measurements (2014)*



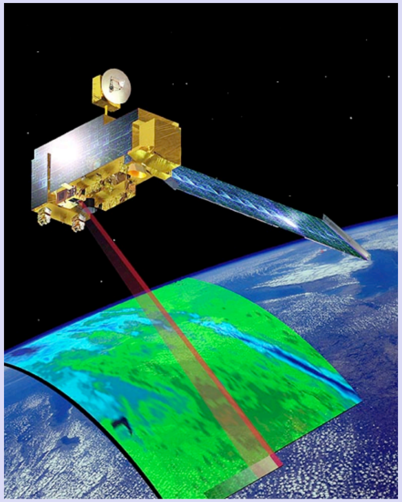
**GRACE**
*Gravity Recovery and Climate Experiment (2002)*



**SMAP**
*Soil Moisture Active Passive Satellite(2014)*

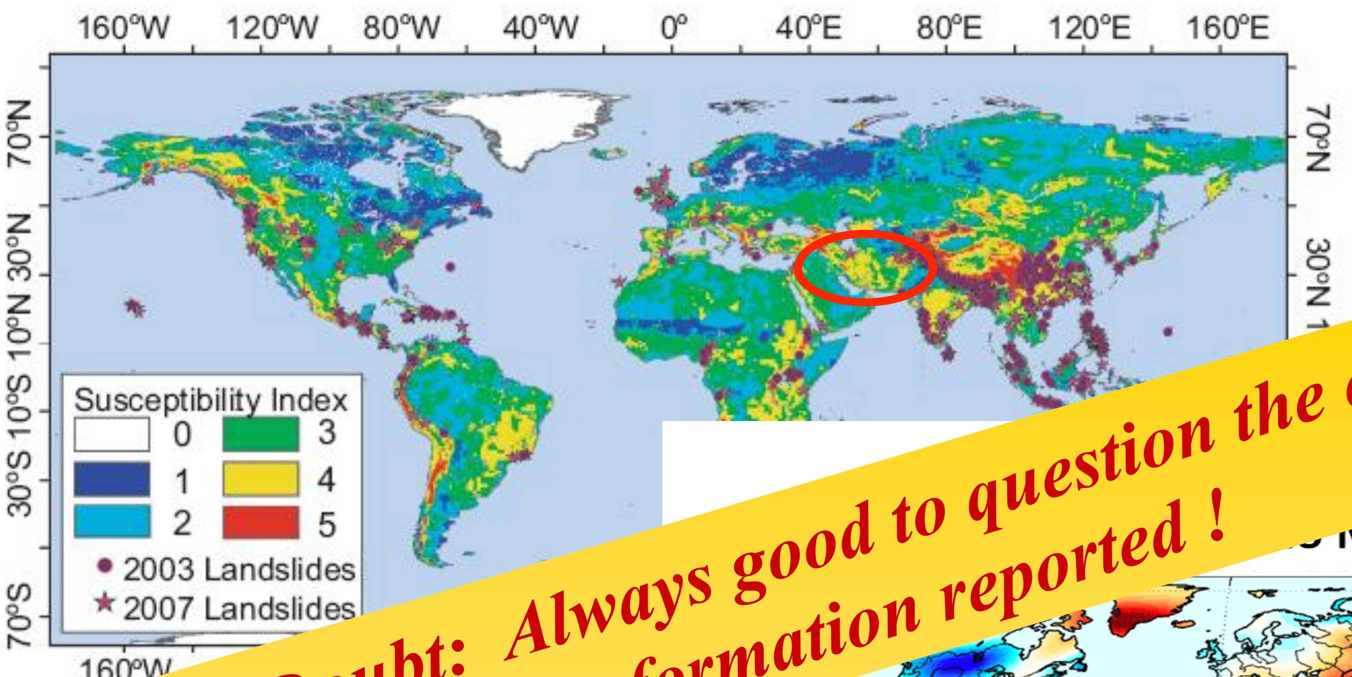


**SWOT**
*Surface Water and Ocean Topography (2020)*

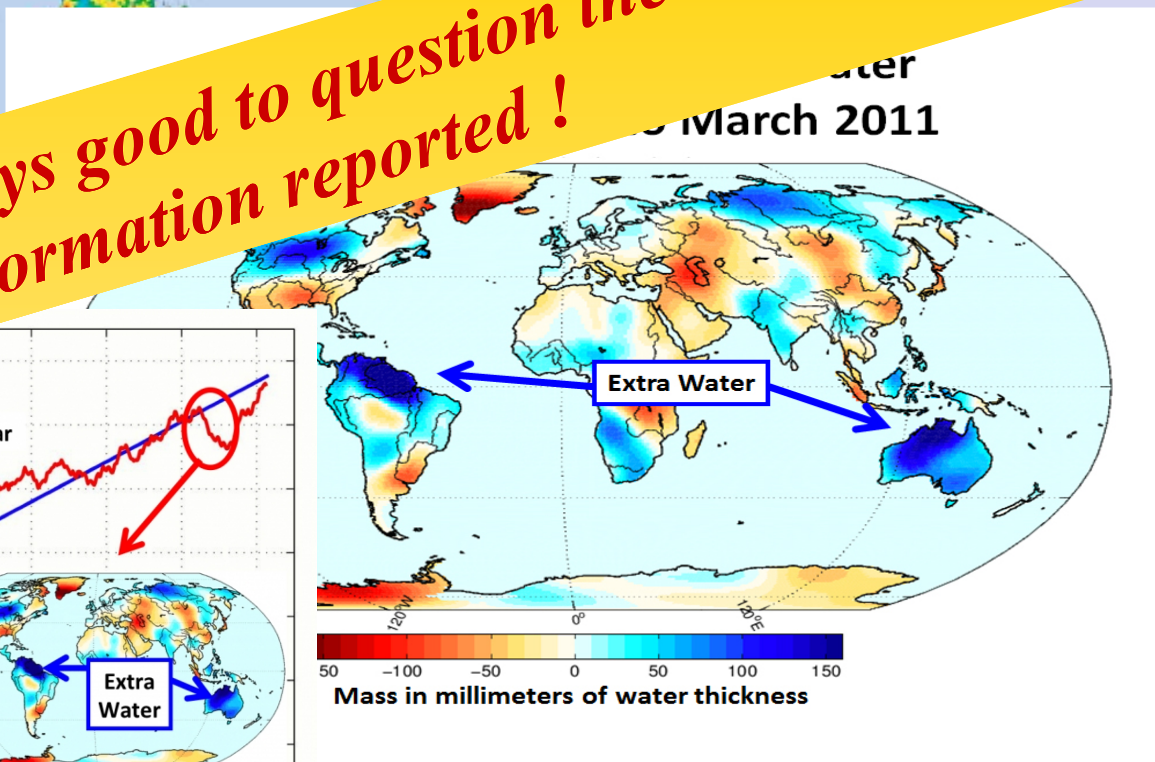


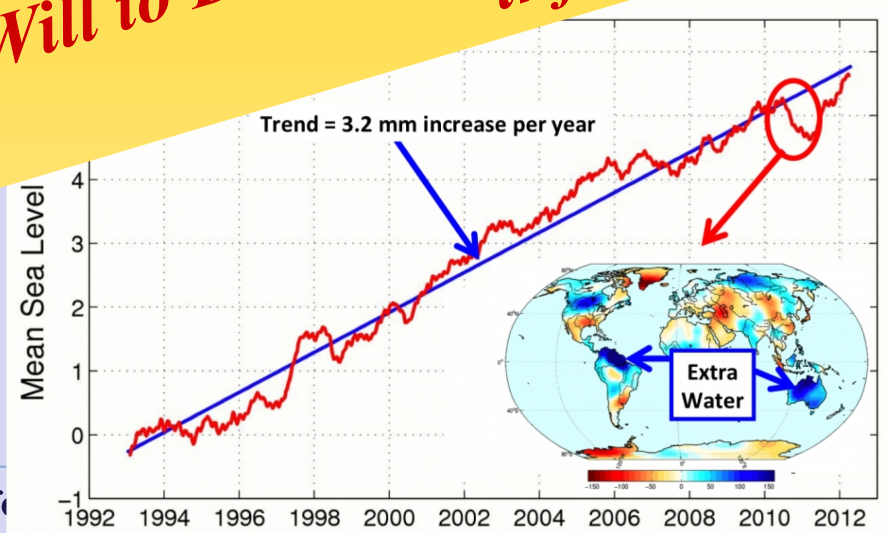
**MODIS**
*Moderate Resolution Imaging Spectroradiometer (1999) , (2002)*

# *Landslide Risk map:*




**Will to Doubt: Always good to question the credibility of information reported !**



# What is the Message?

• ***Despite advances to date, predicting the future Hydro-Climate variables will remain a major challenge:***

• ***Future is complex and observing and modeling its ... challenging. So, "have a will to doubt ... "generated" by models.***

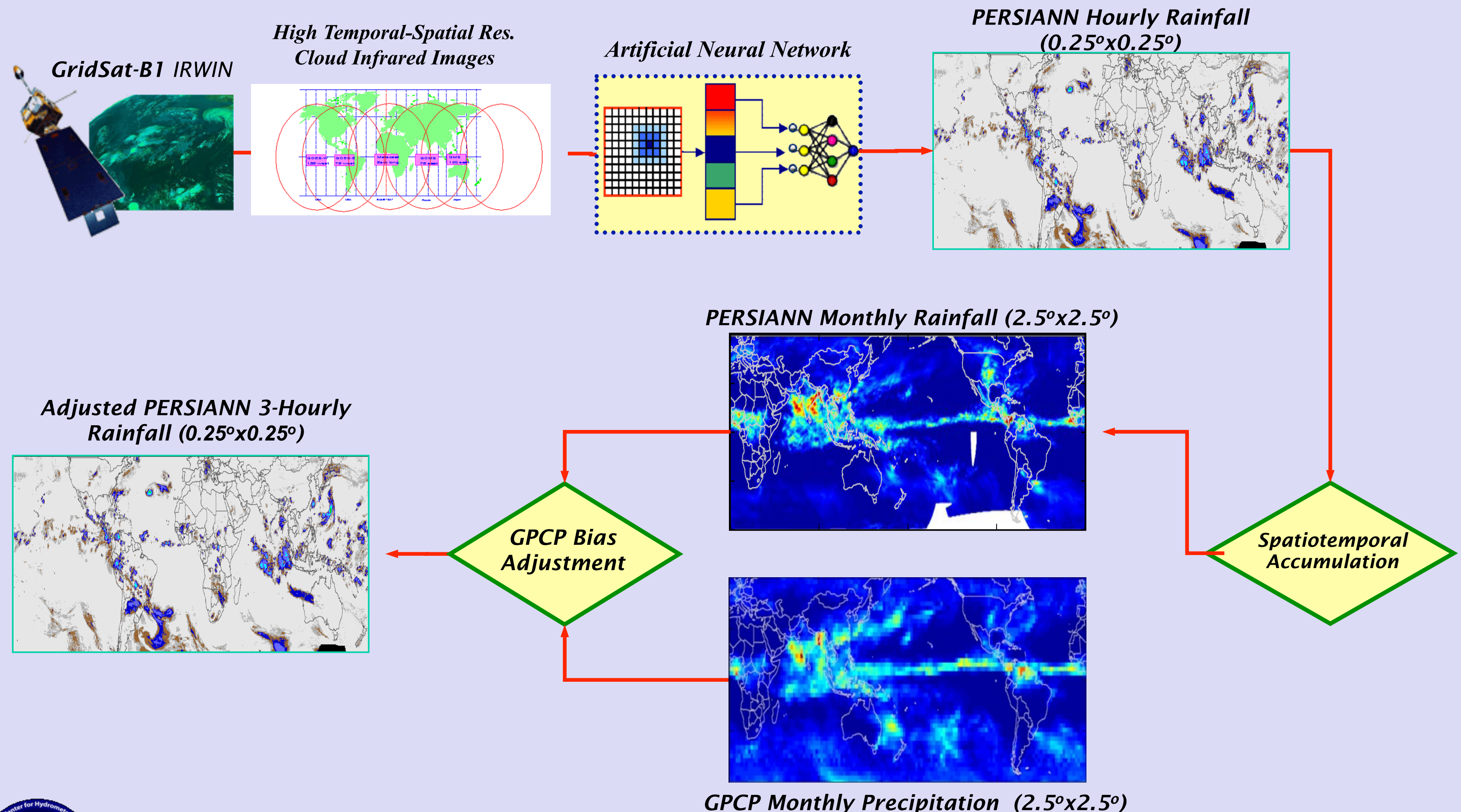
**Factoring in Resiliency in water resources system's design and planning is still the safest approach!**

• ***Long-term and sustained observation programs are critical, especially for model verification. Without some degree of verifiability, hard to expect their use***


*Somewhere in New Mexico, USA - Photo: J. Sorooshian*

# Back up slides

# *Bias Adjustment of PERSIANN Estimates*



# CHRS Web Usage Stats

- **G-WADI interface usage**: http://fire.eng.uci.edu/gwadi_stats.html

  **Number of Distinct hosts served: 44,067** (Since Jan.1, 2010 )

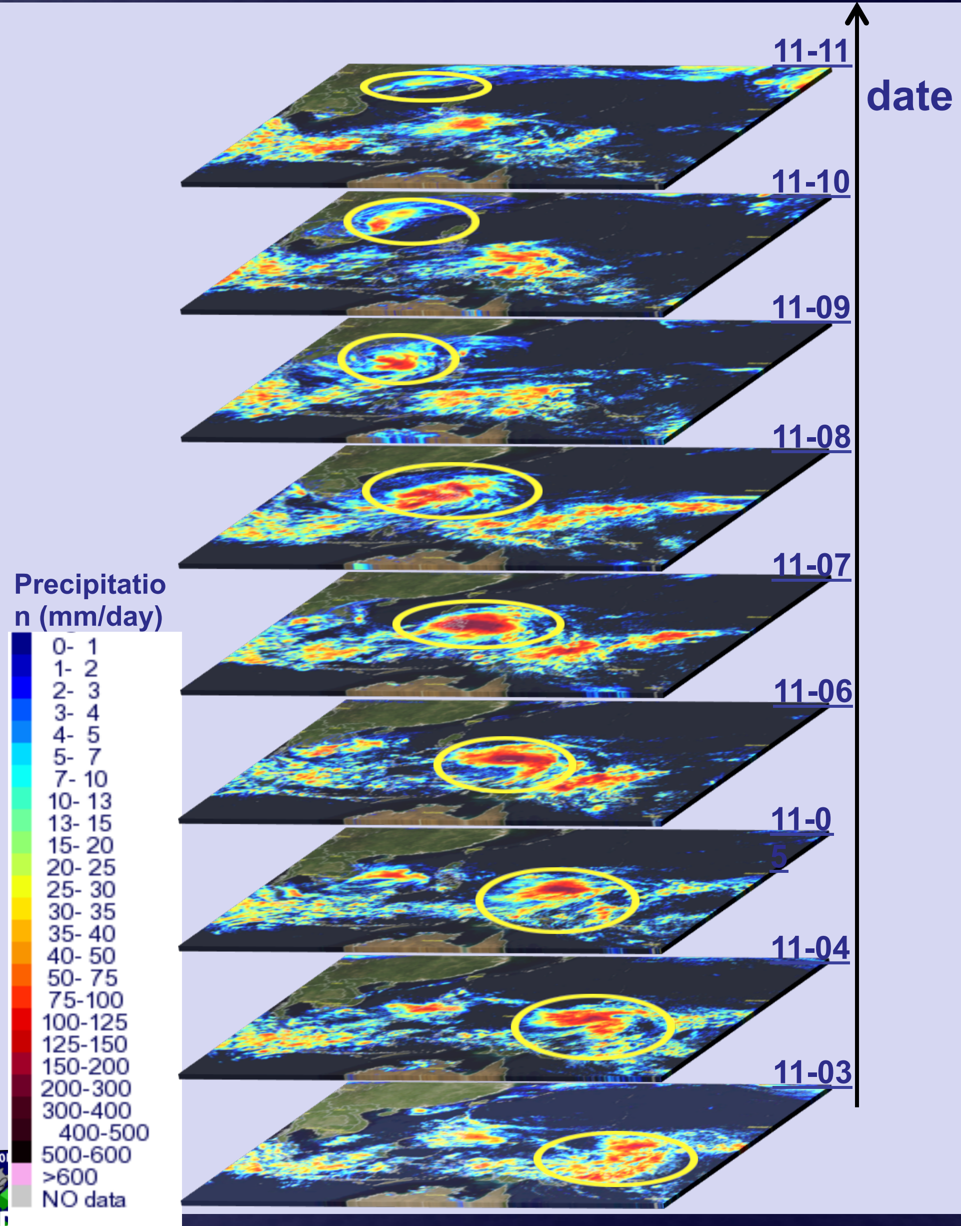
| Year | #requests | #pages | Volume (GB) |
|---|---|---|---|
| 2010 | 663,957 | 116,599 | 348.39 |
| 2011 | 970,985 | 203,599 | 366.51 |
| 2012 | 1,391,260 | 305,269 | 390.09 |
| 2013 (10/17) | 1,664,713 | 264,864 | 417.58 |

- **HyDIS interface usage**: http://fire.eng.uci.edu/hydis8_stats.html

  **Number of Distinct hosts served**: **13,231** (Since Jan.1, 2010 )

| Year | #requests | #pages | FTP d/loads |
|---|---|---|---|
| 2010 | 238,771 | 101,202 | 835 |
| 2011 | 313,328 | 201,640 | 1086 |
| 2012 | 311,953 | 225,850 | 1521 |
| 2013 (10/17) | 137,154 | 71,056 | 1585 |

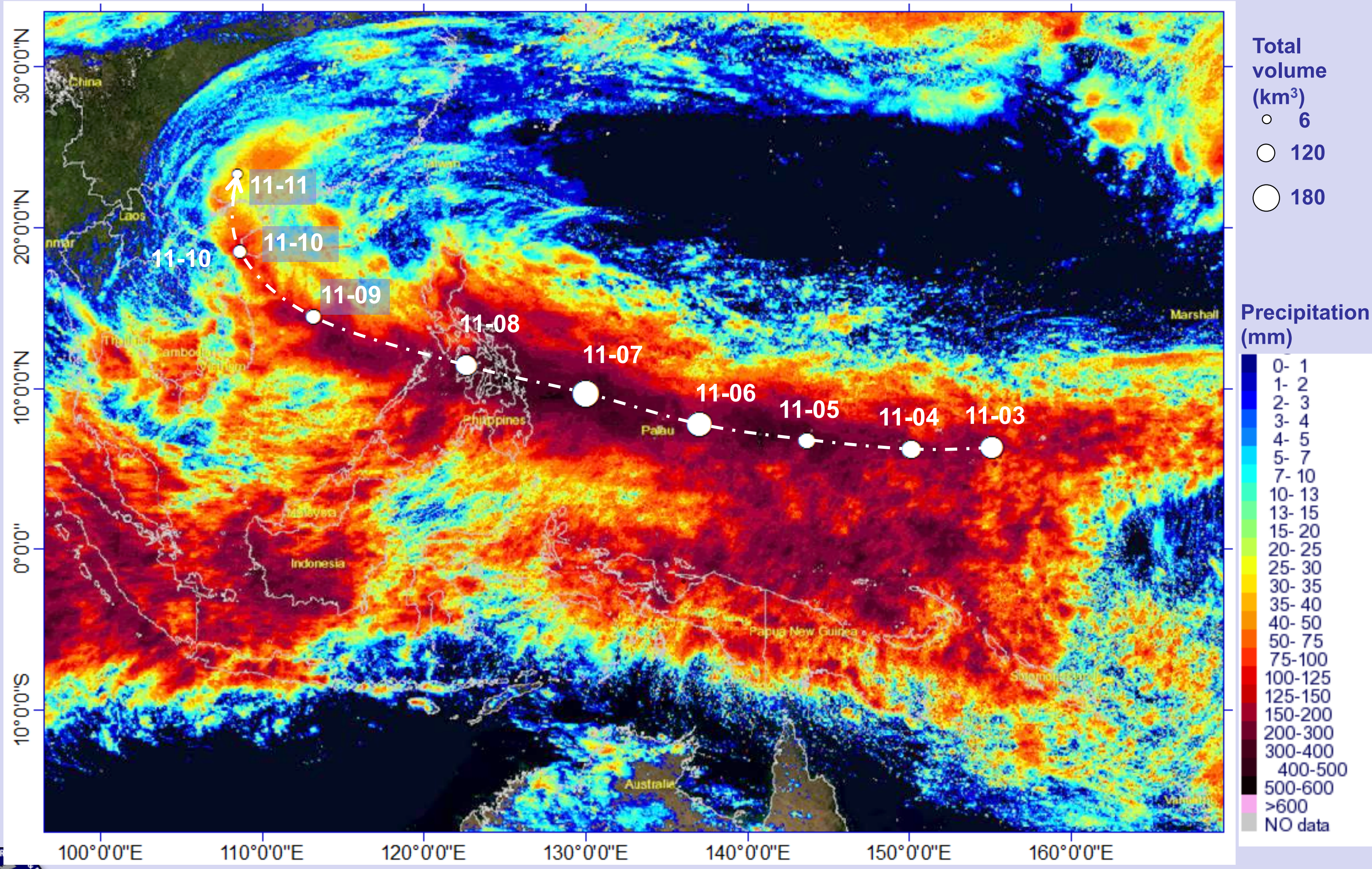
# Daily precipitation (mm/day) of Typhoon Haiyan



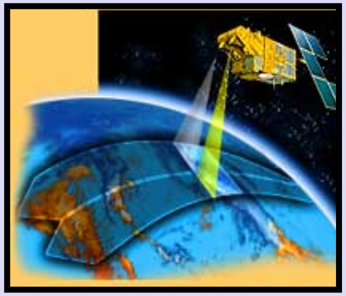

## Tracking characteristics of Typhoon Haiyan

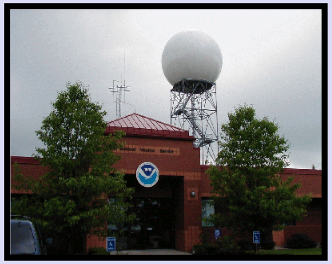
| **Date** | **Max Precip. Intensity** (mm/d) | **Total Volume** (km3) |
|---|---|---|
| 11/3/2013 | 243.67 | 143.254 |
| 11/4/2013 | 265.65 | 114.829 |
| 11/5/2013 | 332.88 | 108.398 |
| 11/6/2013 | 328.25 | 150.658 |
| 11/7/2013 | 360.94 | 184.89 |
| 11/8/2013 | 320.47 | 126.253 |
| 11/9/2013 | 220.7 | 53.126 |
| 11/10/2013 | 130.69 | 24.673 |
| 11/11/2013 | 70.27 | 6.233 |

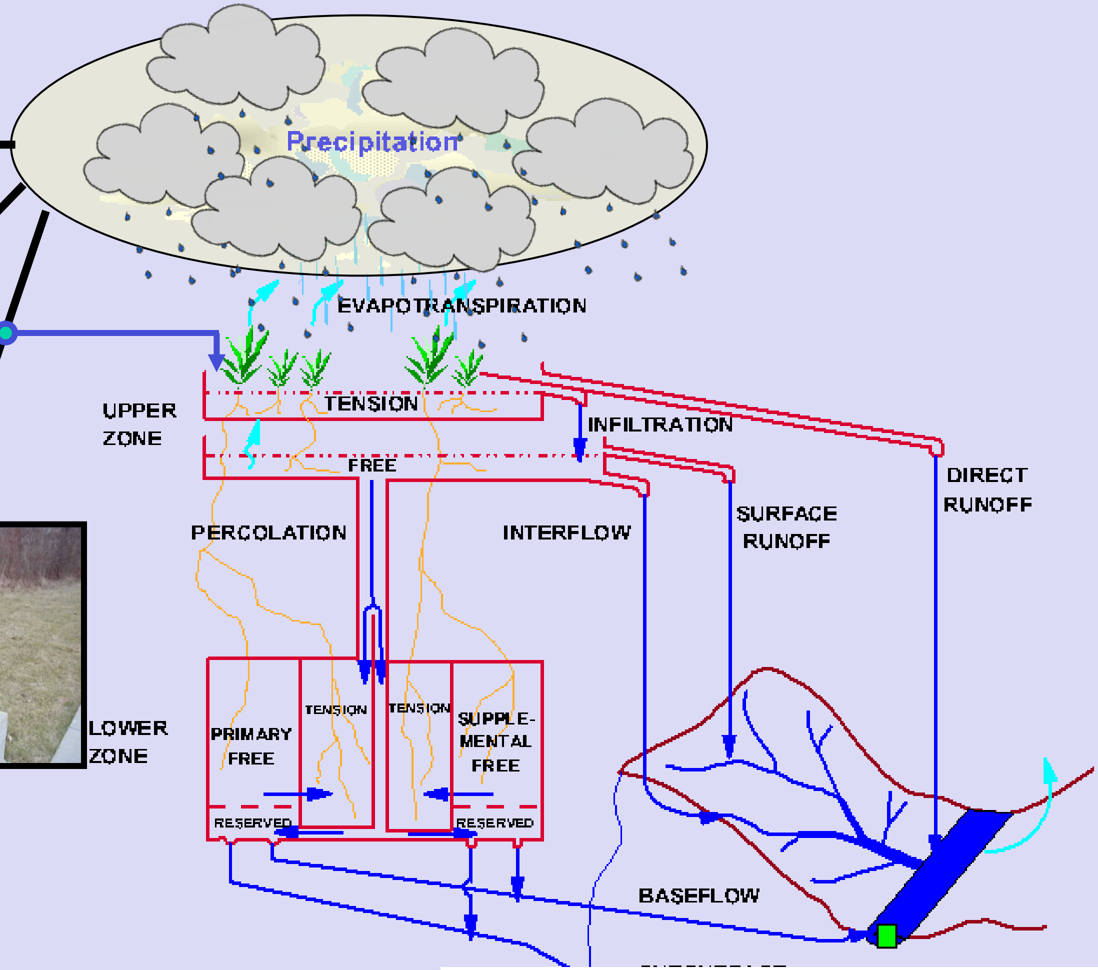
# Typhoon Haiyan – Total Accumulated Precipitation (mm)

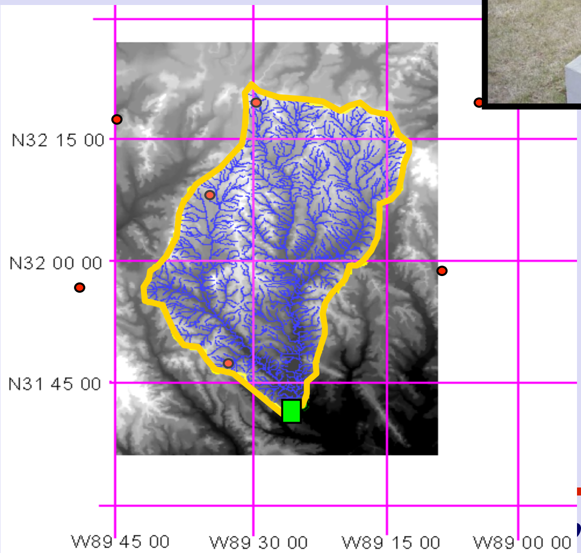


# Basin Scale Precipitation Data Merging

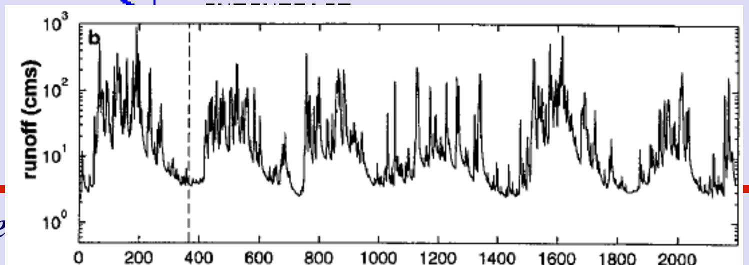




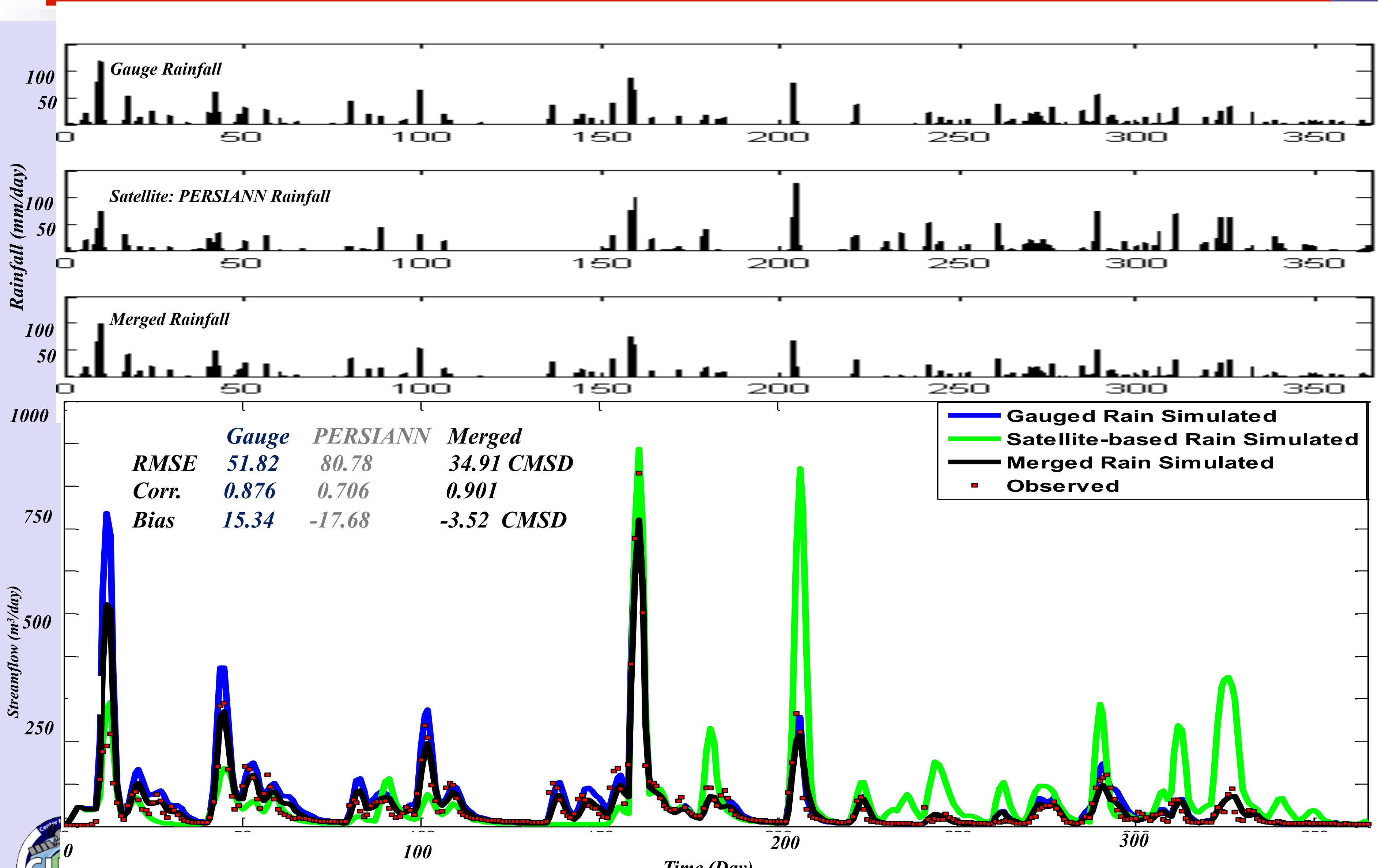




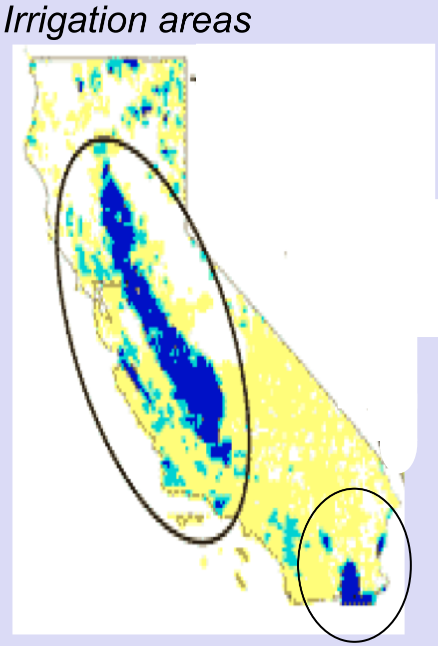
# Runoff Forecasting from Gauge, PERSIANN, and Merged Rainfall



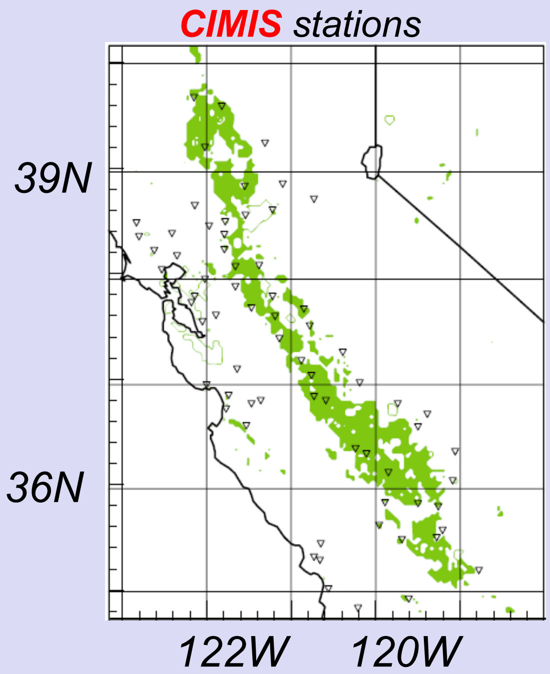
# Large-Scale Irrigation and Incorporation in Models

## Impact of Irrigation

# "Observed" vs "Model-Generated" Data



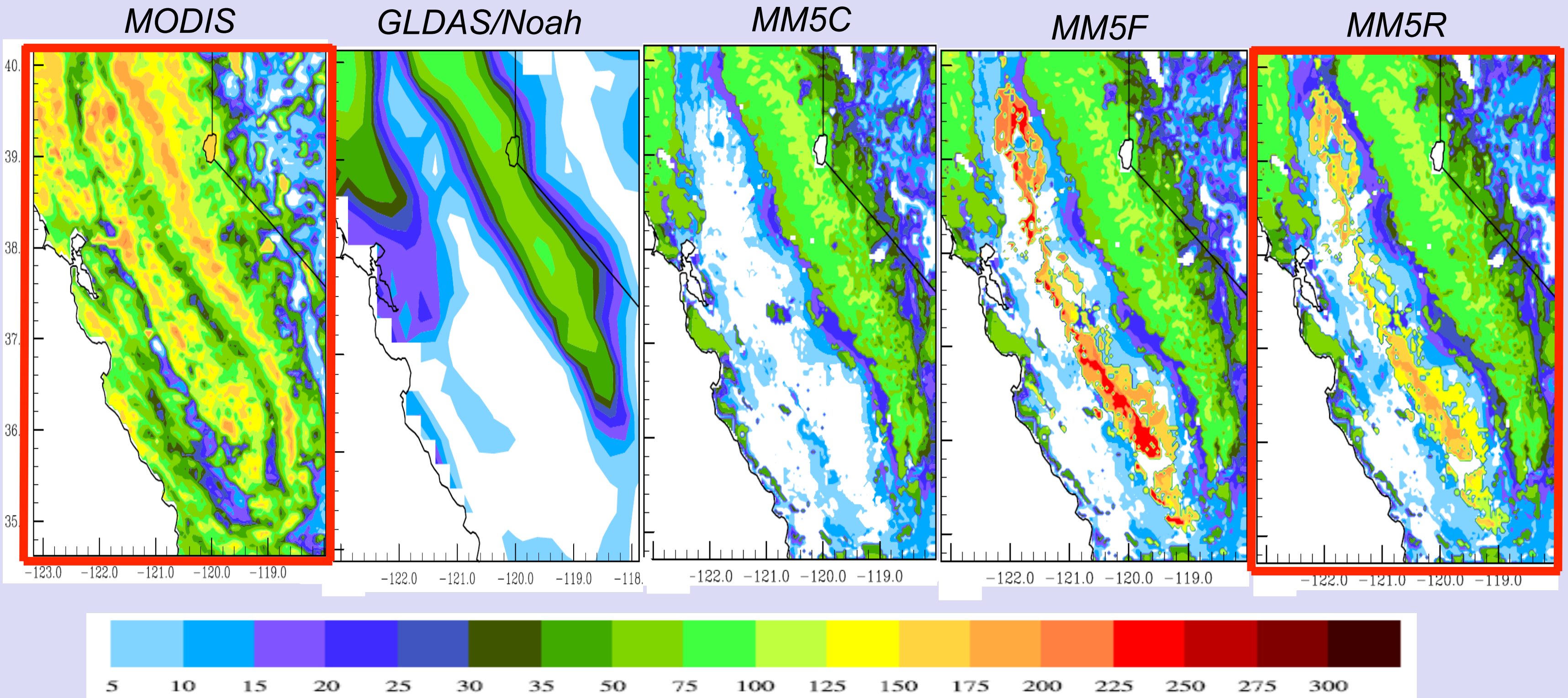





## Studies over California's Central Valley Irrigation Region

*Sorooshian et al. 2011 & 2012*

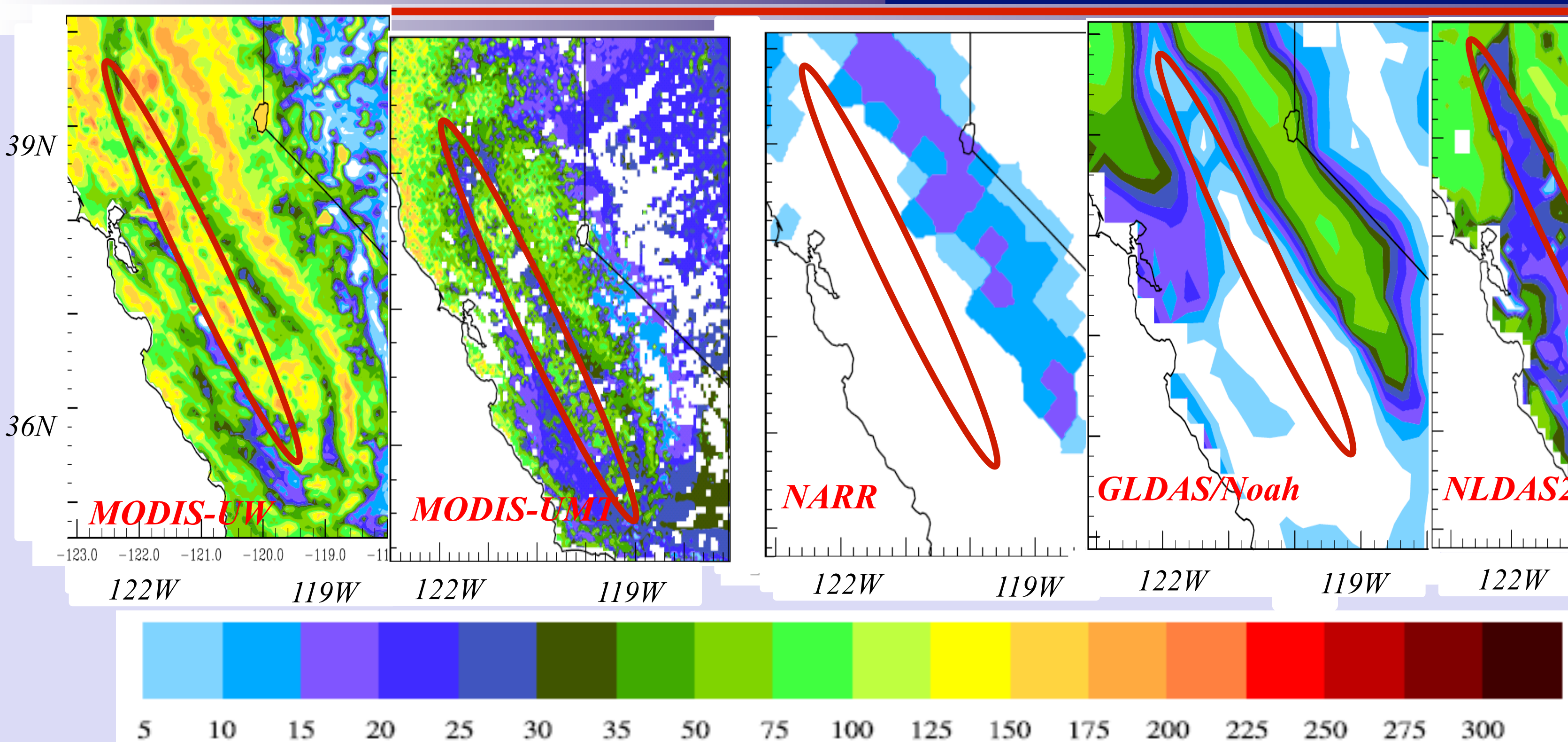
# Actual ET comparison-spatial distribution – JJA 2007




**Monthly ET (mm/month)**

*Results from MM5, with more realistic irrigation scheme, show significant improvement in capturing ET over irrigated Central Valley in California (compared to MODIS - ET estimates). MM5F overestimated.*

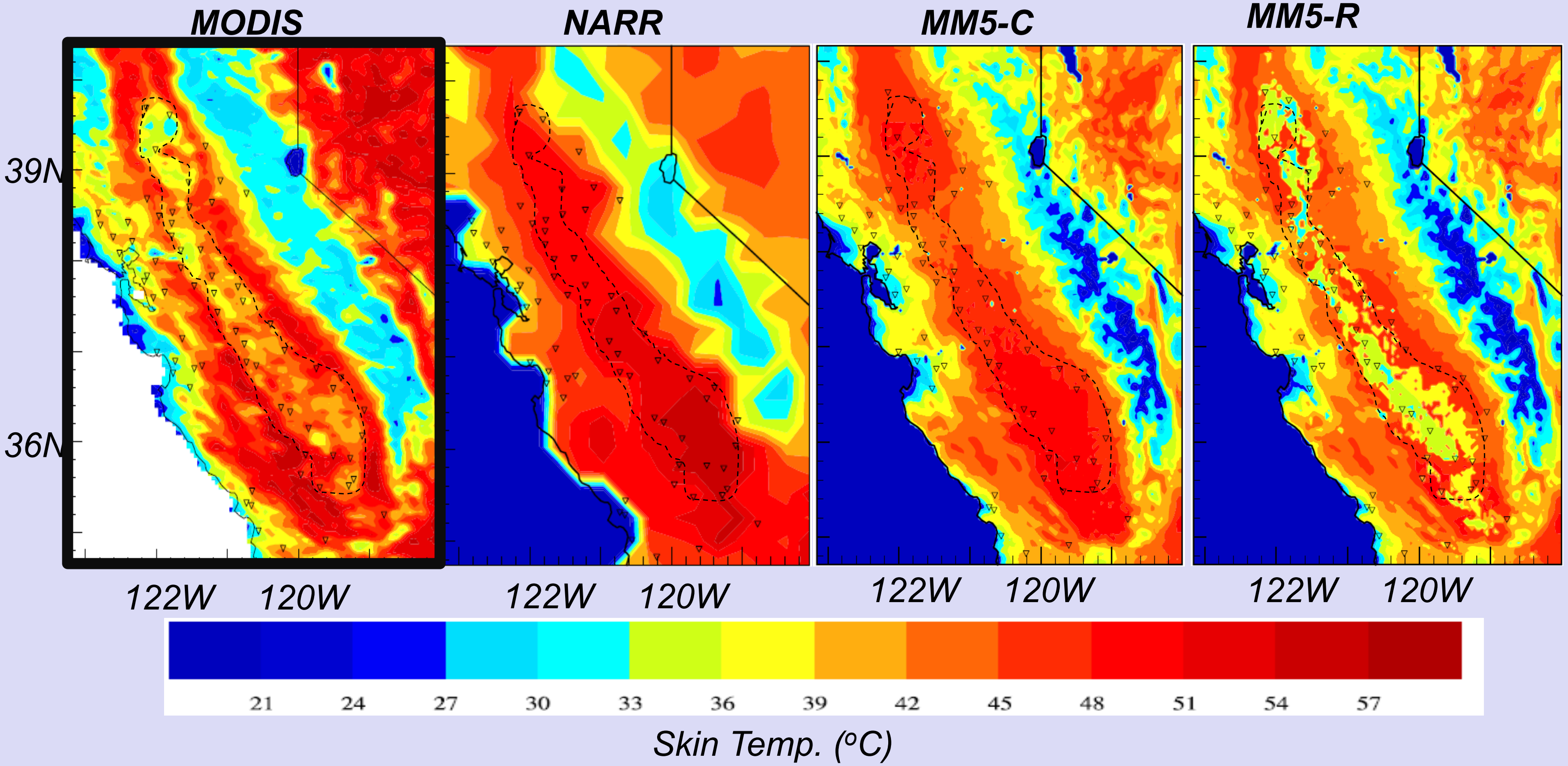
# Actual ET Estimates From Different Data sets– JJA 2007




2007 JJA Monthly ET (mm)

Li et al, 2011

# Mean skin surface temp. at daytime in June, July and August, 2007.




*Adding irrigation into RCM (MM5), Improves the model's ability to simulate, more closely, the temperature patterns observed by MODIS*

*Sorooshian et al, (JGR 2011)*

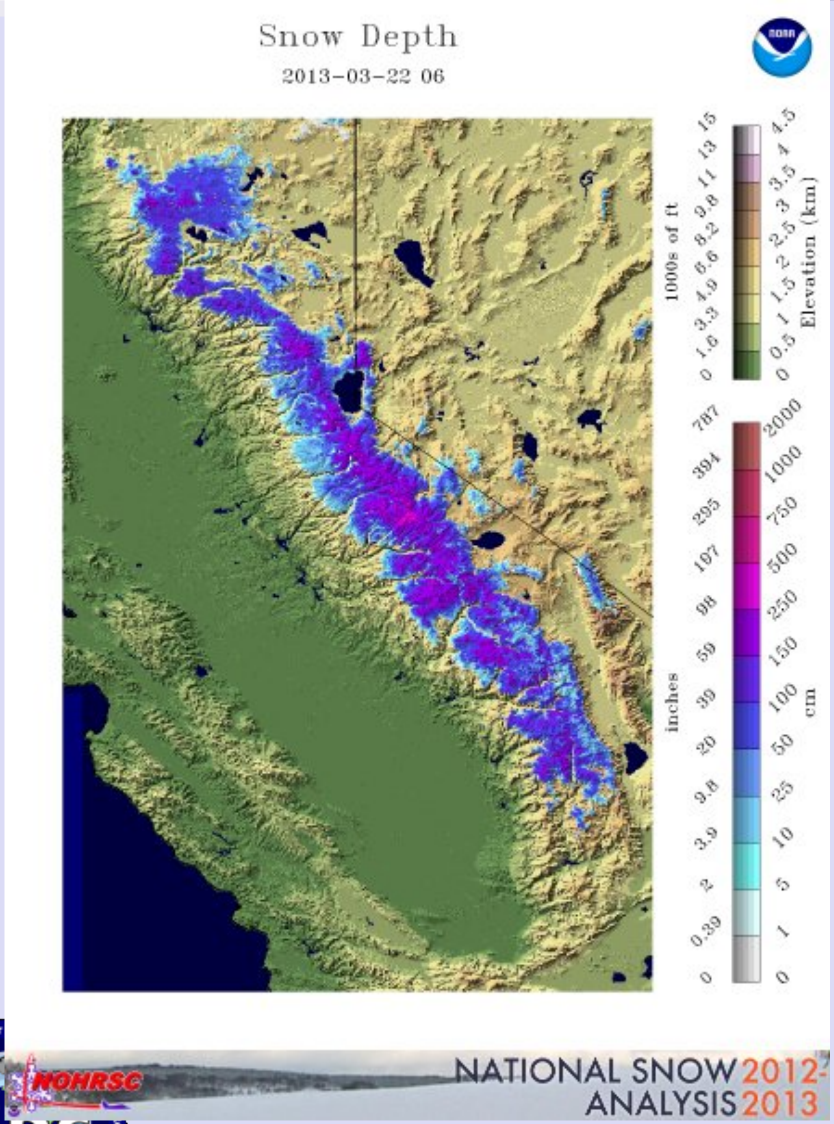
# *In a nutshell!*

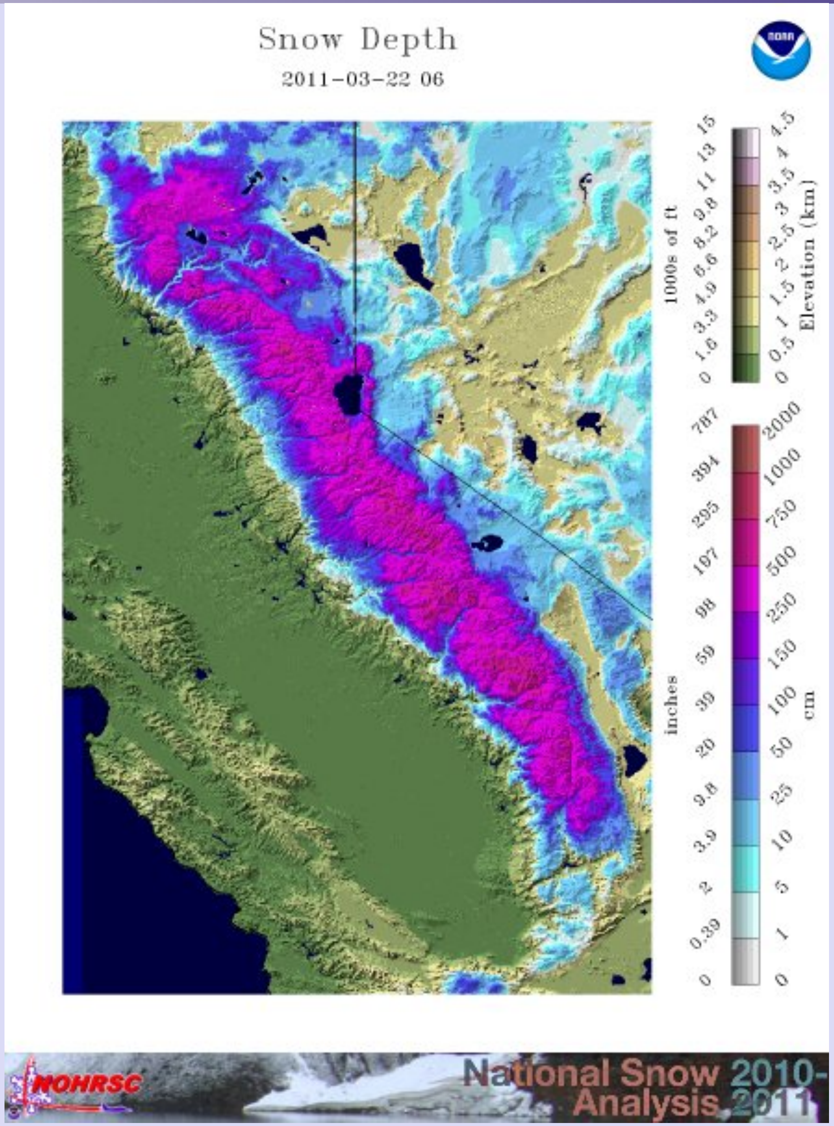
- ***ET Underestimation by MM5 control run is roughly about 10 million Ac-Ft of water/yr***
- ***ET Overestimation by MM5 with "full-saturation" irrigation is about 6.5 Million Ac-Ft/yr***
- ***Use of the realistic irrigation scheme results in only 1.5 Million Ac-Ft/yr of overestimation.***

**placed in Societal context *:***

**Roughly speaking, the amount of ET underestimation equals supply requirement of 13 million households and the overestimation covers the needs of 9 million households per year.**

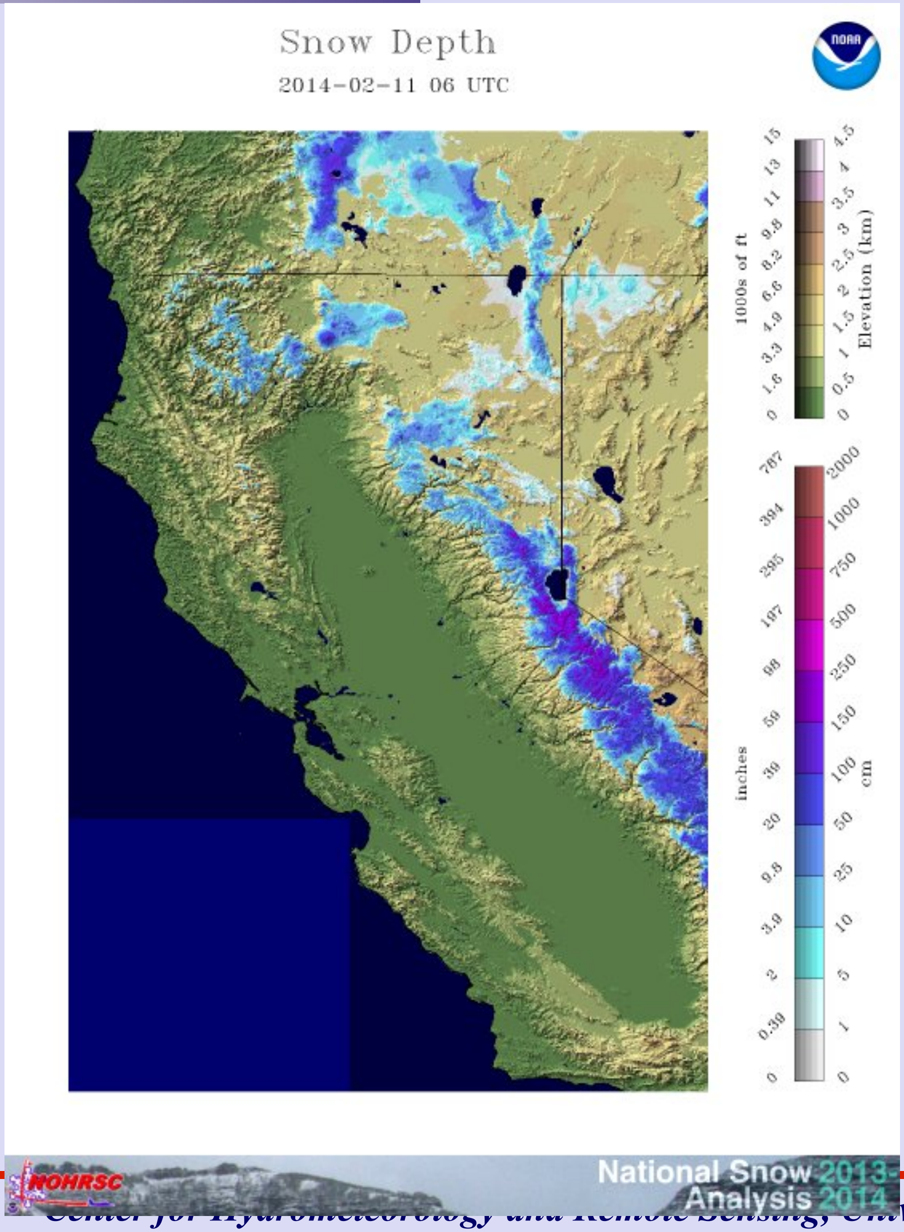
# MODIS Snow Depth(inches) for California



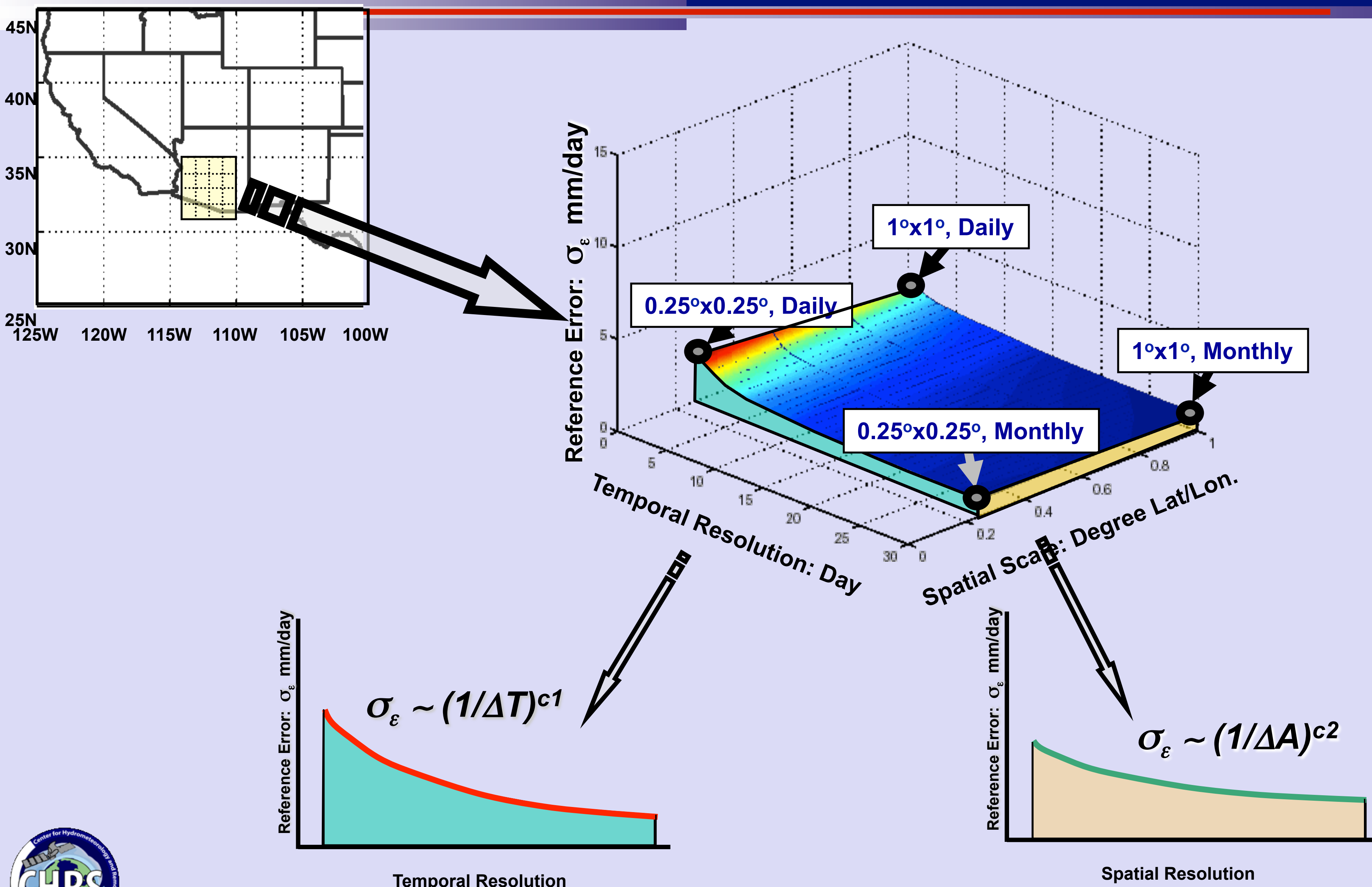




Source: http://www.nohrsc.noaa.gov

# Current Snowpack: After Early February Storm



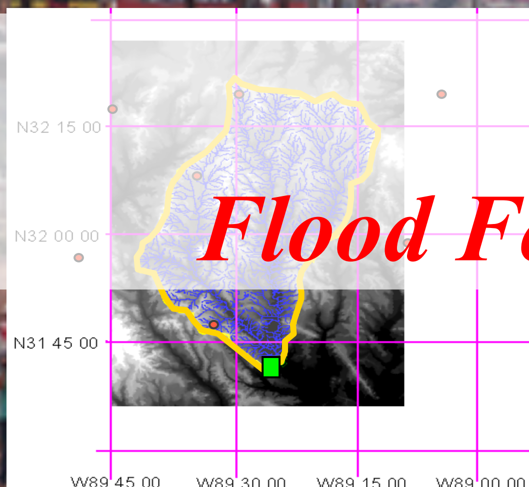
# Spatial-Temporal Property of Reference Error



# *Satellite Rainfall Estimation for Operational Use*

Streamflow forecasting of a catchment in US using UCI-PERSIANN rainfall Estimates for use in the US National Weather Service Runoff Forecasting System (NWSRFS).

## *Promising: Flood Forecasting Example*



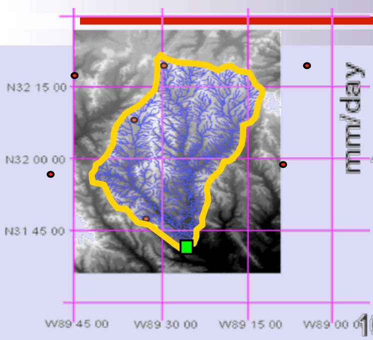

Gages used by NWS

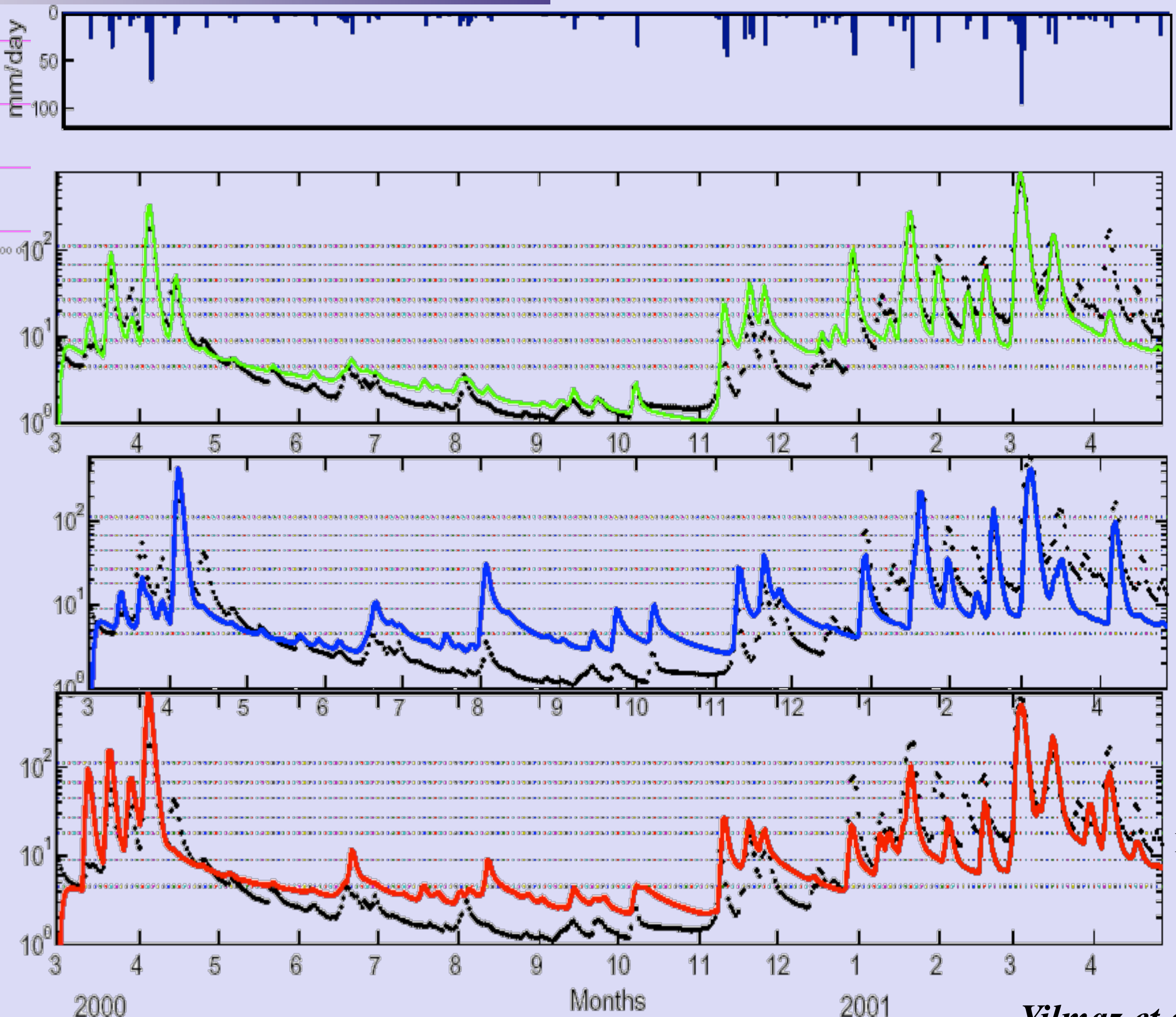
*Leaf River Near Collins*
*Mississippi*
*USGS # 02472000*

*Basin Area : 753 mi²*


***Yilmaz et al. JHM 2005***

# Satellite Rainfall Estimation: Research at UC Irvine

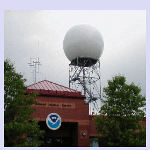



**RAINGAGE**

Corr =0.95
RMS =23.9
BIAS =-1.32

**RADAR**



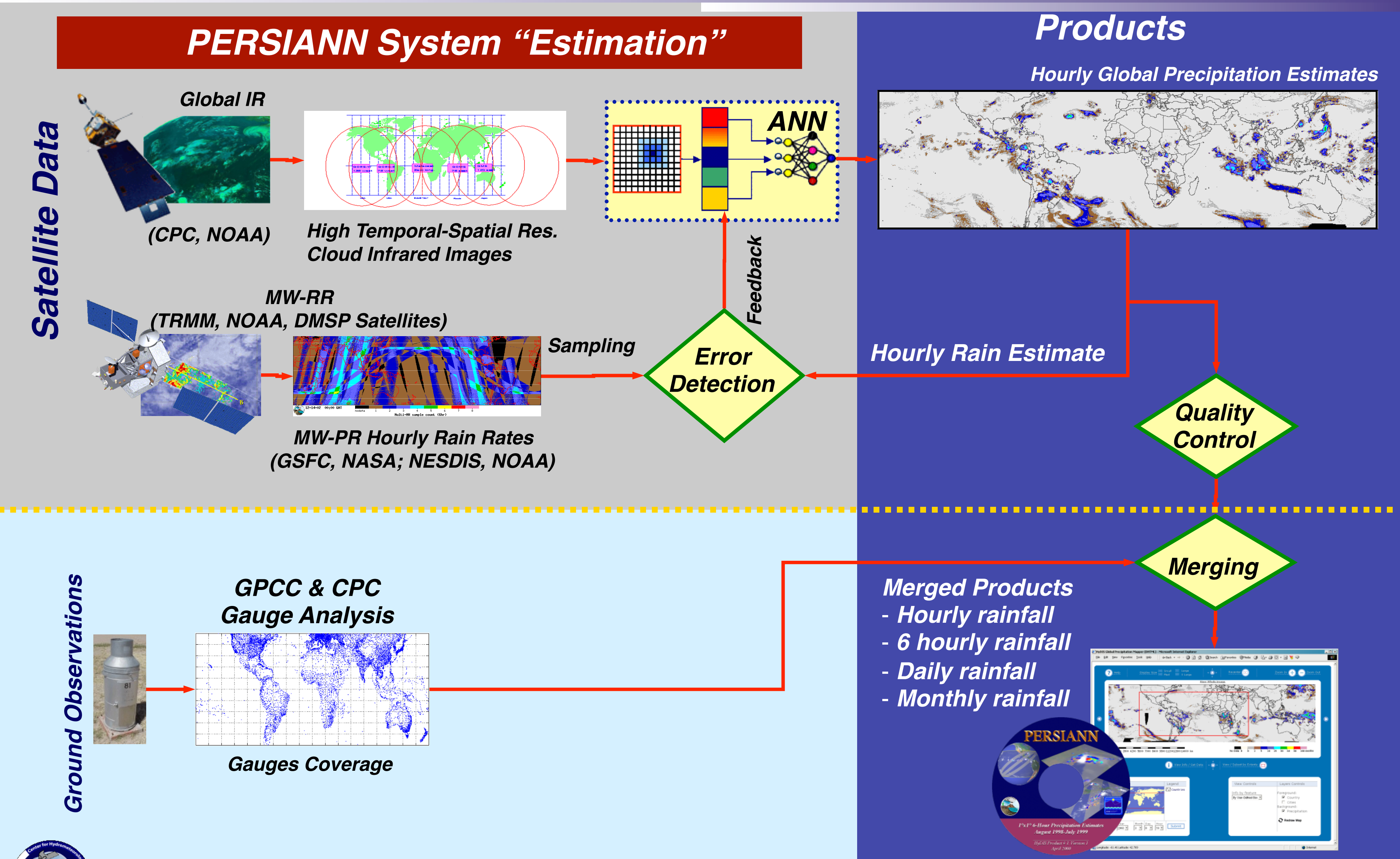
Corr =0.92
RMS =28.8
BIAS =-6.74

**PERSIANN**

Corr =0.94
RMS =22.6
BIAS =-5.15

*Yilmaz et al. JHM 2005*

# Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)




Center for Hydrometeorology and Remote Sensing, University of California, Irvine